Wheat Research: Today's Investment—Tomorrow's Hope

# The National Wheat Research Conference

Beltsville, Maryland, October 26 - 28, 1982

# Proceedings

# THE NATIONAL WHEAT RESEARCH CONFERENCE

Presented by

The National Association of Wheat Growers Foundation

in cooperation with

The Agricultural Research Service, USDA
and
The National Wheat Improvement Committee

October 26 to 28, 1982
Beltsville, Maryland

National Association of Wheat Growers Foundation
Suite 300, 415 Second Street, N.E.
Washington, D.C. 20002

THE WHITE HOUSE

WASHINGTON

October 20, 1982

It is a pleasure to extend warmest greetings to wheat producers, agricultural researchers, representatives of the United States Department of Agriculture, and guests gathered for this National Wheat Research Conference.

I welcome this opportunity to underscore my Administration's commitment to the continued prosperity of American agriculture.

To this end we are dedicated to basic agricultural research and are determined to improve its effectiveness by establishing national priorities and targets in planning and executing USDA's intramural agricultural research programs. Agricultural research must be rooted in a partnership among the Federal Government, the states, and the private sector. Such a partnership will help assure our country's continued agricultural prosperity.

The National Wheat Research Conference is an encouraging step in that direction. I believe that your efforts at these sessions will have a positive impact on American farm productivity and on the ability of the world to sustain a growing population.

You have my best wishes for a most enjoyable and productive meeting.

Ronald Reagan

CONTENTS

# WELCOME TO BELTSVILLE AGRICULTURAL RESEARCH CENTER

P. A. Putnam, Director
Beltsville Agricultural Research Center
Agricultural Research Service
U.S. Department of Agriculture
Beltsville, Maryland

Welcome to the Beltsville Agricultural Research Center, the U.S. Department of Agriculture, Agricultural Research Service's major research facility. It is appropriate that the National Wheat Research Conference (NWRC) has chosen to meet at Beltsville because of the mutual national interests in Agricultural Research. Like NWRC, the Beltsville Agricultural Research Center (BARC) represents the national and international importance of wheat and the USDA's Agricultural Research Service's (ARS) national and international agricultural research mission. Beltsville's research program represents at varying levels of intensity most of the ARS national research programs. The over 400 research scientists located at Beltsville's 7,000 acre "farm" conduct research on subjects ranging from our basic natural resources of soil, water and air, through the major economic plants and animals to postharvest technology and human nutrition. There is an emphasis on basic long-term research with a balance of enough applied research to maintain that necessary contact with industry and consumer needs. BARC, the largest and most visible of the ARS locations is organizationally a part of the Northeast Region and one of 147 locations in the ARS system.

Our scientists are pleased with their continuing accomplishments, some of which are listed in the Center brochure and some of which are illustrated in the exhibits in the foyer. These accomplishments have been possible because of the breadth of scientific expertise at Beltsville and the very convenient cooperative opportunities with scientists located in the eight nearby university campuses and the five nearby Federal research facilities. In addition, our scientists have formal cooperative relationshpis with scientists in over 30 of the State universities and informal cooperation with many more scientists in the State, Federal, and industrial research community. These contacts and those with other Federal agencies, industry, producers, and associations such as yours assure that our research programs will remain on track.

Our location in proximity to our Nation's Capital and to three major airports assures the visibility and accessibility of several taxonomic and working collections maintained by the Beltsville scientists. I am referring to the National Collection of Insects (cooperative with the Smithsonian), the National Parasite Collection, the World Small Grain Collection, and outstanding collections of fungi, nematodes, seeds, and nitrogen fixation bacteria.

The World Small Grain Collection should certainly be familiar to many of you. It is a working collection curated by Dr. David Smith and it is located in one of our 50 some laboratories called the Germplasm Resources Laboratory. Personnel in this laboratory introduce (through the Plant Introduction Officer, Dr. George White), evaluate, distribute, and exchange germplasm needed in research and guide scientists in locating sources of germplasm and crop collections. They maintain over 80,000 accessions of wheat, oats, barley, and rye, and 15,000 rice accessions.

Wheat research at BARC is being conducted by Drs. Steve Baenziger, John Moseman, and James Tommerlin. These scientists are studying the genetics and pathology of wheat. They collect, evaluate, and develop wheat germplasm and coordinate the International Rust and Powdery Mildew Nurseries. They are a part of the Field Crops Laboratory which along with the Germplasm Resources Laboratory is a part of the Plant Genetics and Germplasm Institute--one of the eight Institutes at BARC. The Germplasm Resources Information Network (GRIN) Unit is attached to the Institute Office. As you know, this is a data base management unit that is just implementing its activities.

The BARC Director's Office, the Institutes, Laboratories, and Units work with our ARS National Research Program Coordinators on the ARS National Program Staff on a continuing basis to keep them informed of research program developments and needs and to obtain feedback on agency research priorities and anticipated shifts in program emphasis or support.

I have briefly touched on Beltsville's national research mission, how we fit into ARS/USDA organization, how we are organized at the Beltsville level, the breadth of our research programs and some of the advantages of the Beltsville location. You have a very full agenda, but I do hope that you will find time to take a closer look at <u>your</u> Beltsville research facility and program. I say "yours" because we think we have been successful in maintaining a truly national agricultural research program and we want you to help us in that objective. May your conference be pleasant, informative, constructive, and highly successful.

## PURPOSE OF THE NATIONAL WHEAT RESEARCH CONFERENCE

Glenn Moore
President, National Association of Wheat Growers Foundation
Willard, Montana

As a wheat producer from Willard, Montana, and president of the National Association of Wheat Growers Foundation, I have been asked to present the opening remarks on the purpose of the National Wheat Research Conference.

I believe that each of us must leave the world just a little bit better than the way we found it. One method of accomplishing this is to continually strive to improve the wheat industry. Those involved in the wheat food chain have an important obligation in an era when world population is rapidly increasing.

It is also my belief that the only way that we can work to feed the world better than we are now and contribute to world peace is for every segment of the wheat industry - energy, chemicals, machinery, farming, transportation, processing, distribution, and all the others - to be healthy and viable. This requires research to back up these segments, communication to keep them all informed, an educational process to bring new ideas and new concepts to fruition, and also communication to stress the importance of a sound wheat economy to the nation as a whole.

I have devoted a large portion of my life to working for wheat growers beyond my farm gate. Without being presumptuous, I am pleased to have been one of the founders of the NAWG Foundation. And I was involved, just three short years ago, in the Foundation's purchase of a three-story office building to house the Foundation and the National Association of Wheat Growers in Washington, D.C. The building and its location on Capitol Hill provide a highly important visible and physical presence for the wheat industry in the eyes of the nation's lawmakers.

This research conference is the first major project of the Foundation. It evolved from a need to: 1) draw attention to the ongoing accomplishments of research; 2) increase awareness of future research needs and prioritize these needs into goals; 3) bring public and private researchers together with growers who are vitally interested in making use of research achievements; and 4) create an awareness of future research goals to gain support for the funding essential to meet these goals.

I hope this first of many wheat research conferences goes far beyond focusing on increased productivity. While productivity is important in maintaining a comparative advantage in world markets, ways must be found to decrease production costs, increase nutritional qualities, develop new products, and maintain the ability to produce for a growing world population.

We have an outstanding program that brings together the broadest spectrum of the public and private wheat research community ever gathered. I know you are as anxious as I am to hear the presentations of those participating in the workshops.

A communications committee, comprised of key professinal communicators and chaired by Jim Sample of Du Pont is in place to create essential press coverage for the participants and the conference.

Various agribusinesses and State wheat organizations have provided overall conference funding through sponsorships.

Over 50 individuals have prepred presentations and material for the conference -- every one a true contributor to today's and tomorrow's wheat research.

To make certain that the proceedings of this conference are communicated to a broad audience, we have asked all speakers to avoid highly technical presentations and to keep their remarks precise, to the point, and within the time frame allowed.

The USDA's Agricultural Research Service and the National Wheat Improvement Committee have enthusiastically supported this conference. I would like to personally thank these parties for their support on behalf of the NAWG Foundation and the entire membership of the National Association of Wheat Growers.

In closing, I want to reinforce the single most important goal of this and future conferences -- to establish a national priority for essential wheat research. That is the ultimate challenge and will be the ultimate success.

# POTENTIAL FOR A YIELD INCREASE IN WHEAT

Byrd C. Curtis

Director of the Wheat Improvement Program,
International Maize and Wheat Improvement Center (CIMMYT)*
El Batan, Mexico

It is both a privilege and an honor for me to be able to participate in this National Wheat Research Conference. I feel fortunate in having this opportunity to speak about a subject that has long held my interest: the potential for increasing wheat yields, and the need for doing so. As many of you know, I've spent much of my professional life working to increase the yield potential of wheat. During this period, I've witnessed tremendous yield and production gains, not only in wheat, but in many other food crops as well. I've become convinced over the years that agricultural scientific research, far from being played out, still has much to contribute to increasing food production and thereby improving the well-being of mankind. For this reason, I am particularly pleased to see here today such a high representation of public and private organizations concerned with agricultural research; I feel that a continued strong and concerted research and extension effort will definitely be required to meet the food production challenges of the coming decades.

My purpose in delivering this address is not to dwell at great length on past achievements in raising wheat yields, and in so doing perhaps imply that similar gains are to be expected indefinitely. Rather, my intent is to try to present a balanced and realistic picture of where we are today in terms of the production, consumption and trade of wheat on a global basis, how we got here, and what the current trends in these three variables may mean for future research efforts. I'll then focus on some of the more promising areas of wheat research, from which I expect the greatest contributions to increasing wheat yields. Let's begin with a brief look at some of the factors affecting wheat production.

## Wheat Production

On a worldwide basis, the production of wheat has shown a remarkable increase over the last decade. From 1971 to 1981, global wheat production rose by about 115 million tons, roughly a 35 percent increase. This expansion was not smooth, but the trend was strongly upward despite year to year fluctuations. Compared to production levels that prevailed

---

*CIMMYT is a private, nonprofit International Agricultural Research Center, chartered under Mexican law, and a member of the Consultive Group for International Agricultural Research (CGIAR).

around the world in 1971, production increases in developing countries were proportionally much greater (nearly a 50 percent increase). In developed countries, production rose by about 35 percent, but in absolute terms, slightly more than half of the increase in global production occurred in the developed world.

Much of the production increase over the last decade was due to higher yields, which rose by some 30 percent for the world as a whole. Third World wheat producers increased yields by about 40 percent, thanks primarily to the widespread adoption of improved semidwarf wheats and investments in irrigation. Developed countries achieved a smaller increase (about 20 percent), but their yields were generally much higher to begin with.

Other factors, of course, also contributed to this rising production. On a global basis, the area planted to wheat expanded roughly 5 percent, or about 12 million hectares over 1971, and in many countries the percentage increase was much higher. The use of production inputs, primarily nitrogen fertilizer and irrigation water, has risen dramatically. For example, in 1974 the global use of nitrogen fertilizer stood at about 40 million tons. In 1981, only 7 years later, this figure had increased to about 50 million tons, a jump of 25 percent.

Global figures on the amount of wheat land under irrigation are not readily available, but a couple of examples should suffice as an indicator of the increased use of irrigation water. In India, the percent of wheat under irrigation rose from 48 percent in 1966-67 to about 62 percent in 1975-76. In the Punjab, India's main wheat-growing region, the percent of total wheat area under irrigation stood at 84 percent in 1975-76, nearly all of the land that could benefit from large-scale irrigation projects. In its current 5-year plan, India now places its emphasis on developing small-scale irrigation projects, and forecasts an increase in irrigated area of about 17 million hectares. In China, irrigated wheat area increased from 38 million hectares in 1967, to some 48 million hectares in 1977, a 28 percent rise.

The dependability of yield has also increased substantially across environments, primarily due to the distribution and adoption of management-responsive varieties possessing better resistance to diseases, particularly the rusts. In a recent CIMMYT-sponsored comparative analysis of 15 years of international spring wheat yield data, it was conclusively shown that certain high-yielding CIMMYT generally perform better than locally developed varieties across all environments, even in the poor growing environments. One cultivar, Nacozari, can be classified as a "universal variety" that is capable of outyielding most cultivars in all spring wheat environments. The reasons for this kind of performance are essentially twofold: 1) a more efficient utilization of available inputs, and 2) a broad spectrum of resistance to prevalent diseases that make an otherwise fertile environment a low yielding one.

Improved agronomic practices also play an important role in enhancing the dependability of yields. In Turkey, for example, production

nearly doubled between 1971 to 1982, rising from 9 million to about 17.5 million tons. This impressive increase resulted primarily from use of water-conserving cultural practices on the Anatolian Plateau. Varietal changes contributed little to this gain.

Wheat Consumption

Let's look now at the consumption of wheat products. Over the past decade, world wheat consumption essentially kept pace with the increase in available supplies. In the major developed countries, the average wheat demand for all uses has leveled off at about 175 kg per capita per year. In the Third World countries, however, wheat has now become one of the single most important sources of calories, and to a lesser extent protein, in the diets of hundreds of millions of people. In the developing countries,wheat demand has increased by about 73 percent over the last ten years; a phenomenal 5.4 percent annual growth rate that, were it to continue indefinitely, would result in a doubling of Third World demand for wheat every 13 years!

A number of factors have contributed to this explosive increase in the consumption of wheat in the developing world. One is a shifting of tastes and preferences in favor of wheat vis-a-vis rice and coarse grains like maize and sorghum. For example, from about 1963 to 1976 the per capita direct human consumption of wheat in all developing countries rose by about 35 percent, while the increase for rice stood at about 6 percent. Maize showed no increase, and the per capita consumption of millets and sorghum and roots and tubers declined by about 14 and 15 percent, respectively. Another indicator of changing tastes and preferences is found in the fact that an increasing portion of wheat imports, now on the order of 20 percent, are going to tropical countries in Subsaharan Africa, Southeast Asia and Latin America, where wheat is either not produced or is not a traditional crop.

Demographic shifts and changing income levels are also having an impact on consumption patterns in developing countries. Rapid urbanization in the Third World is affecting both consumer food preferences and the relative availability of local versus imported food. Recent evidence from food consumption surveys strongly suggests that wheat consumption is much higher in urban than rural areas, and that wheat products are more important to middle and upper income groups. In general, urban incomes are notably higher than in rural areas, resulting in the substitution of wheat and rice for maize and other coarse grains. Urban consumers also tend to prefer convenience-type foods, such as bread and other wheat products, that require little or no preparation. Urban populations are also more exposed to outside or nontraditional influences, especially Western influences, which can gradually (and sometimes not so gradually) alter local tastes and preferences for everything from clothing to food items.

The importance of urbanization and its impact on the demand for wheat is underscored by the rapid rate at which urbanization is occurring in developing countries. Globally, urbanization in Third World

nations is occurring at an average annual rate of about 4 percent. In Latin America, more than half the total population now resides in urban areas, and wheat consumption has increased substantially. This region (excluding Argentina) now imports over half the wheat it consumes. In the Andean countries of Colombia, Peru, Bolivia, Venezuela and Ecuador, maize is the traditional staple food. Now, largely because of urbanization, these countries consume more wheat than maize, and almost all of it is imported.

The influence of urbanization on wheat consumption is most clearly seen in Subsaharan Africa, where urban growth rates average about 6 percent per year. The consumption of wheat products is increasing at 7 percent per year, even though average per capita incomes and food availability have declined. Nearly all this growth in demand is due to urbanization and the favorable prices for wheat products found in urban areas.

The pressures created by rapidly growing urban populations are often keenly felt by the governments of developing countries, one result being a persistent and widespread government intervention in the marketplace to assure the provision of food to urban consumers at "reasonable" prices. This intervention has almost universally favored wheat, especially at the expense of maize and other coarse grains. In some cases, government policies even favor imported wheat over domestically produced wheat, finding imports to be a relatively easy short-run solution to feeding their growing urban populations.

Subsidies for wheat and wheat flour are a common means of intervention, and in many instances constitute 50 percent or more of the total cost of providing the product to the consumer. Using 1970 as the base year, it is quite revealing to compare unsubsidized bread price indicies of Costa Rica and Hong Kong with the indicies of Brazil and Jordan, where bread was increasingly subsidized during the 1970s. Because of subsidies, the price of bread in Jordan and Brazil dropped by about 50 percent over the last decade. When compared to the prices found in free market countries like Hong Kong and Costa Rica, the consumer cost of bread in Brazil and Jordan has dropped even more. The significance of this price decline is found in the well-documented fact that the consumption of wheat products is sensitive to price changes. Thus, the declining consumer price encourages consumption and contributes to rising demand.

Food aid in the late 1960s and early 1970s, mostly in the form of wheat, has promoted wheat consumption and has resulted in wheat subsidies in many countries. Food aid has declined in relative importance for most developing nations (as a percentage of their total wheat imports), but even so, the effects of early food aid programs are still with us today: urban consumer preferences for wheat products are firmly established, even in some countries where wheat is not a traditional crop, and subsidy programs that were initiated to keep consumer prices from rising too rapidly as government agencies phased in commercial sources of wheat supplies have become institutionalized.

## Wheat Trade

The fact that most of the growth in demand for wheat during the last decade has occurred in the Third World, while more than half of the increase in production (in absolute terms) was accomplished in developed countries, contributed to a considerable expansion in world wheat trade. It grew from about 53 million tons to an estimated 99 million tons per year over the last 12 years, and in 1981/82, developing countries as a group imported some 62 million tons of wheat. The Third World share of global wheat imports has steadily increased and, with only a few notable exceptions (such as India, Pakistan, Turkey and Argentina), the degree of wheat self-sufficiency of developing nations relative to rising demand has actually fallen during the 1970s.

## The Future and the Need for More Research

To this point I've been describing what has happened during the last decade to the production, consumption and trade of wheat, why these changes have come about, and where we now stand. Briefly summarized, these trends are as follows: World production of wheat has undergone a significant increase over the last decade, roughly a 35 percent rise and developing countries accounted for about half of this increased production. World consumption has more or less kept pace with the available supply, although demand for wheat has increased much more rapidly in the Third World. In fact, most of the additional wheat produced in developed countries found its way into export markets, thus contributing to a near doubling of world wheat trade.

The question naturally arises: what do these trends in the production, consumption and trade of wheat mean for the future, especially in light of the fact that global population is likely to double in the next 40 to 50 years? Some futurists predict the entering of a new era, characterized more by food shortages than surpluses, by widely fluctuating prices, and by a steadily widening gap between those who have much and those who have little. Some predict, if not the demise, certainly a decline in the relative importance of energy-intensive, highly mechanized agricultural technology. They see the high-payoff agricultural technologies of the future being those that result in dependably high yields via more labor than capital-intensive techniques. These technologies will involve multiple cropping practices and will be resource-conserving in nature.

I suspect the future will see a mixture of technologies, each appropriate for the cirumstances and constraints under which it is applied, and each designed to obtain the maximum yield possible per unit of land area per unit of time. Certainly, multiple cropping will have an increasingly important role to play, particularly in Third World countries. And the development of high-yielding and yield-dependable varieties of wheat and other crops must keep pace with growing demand.

One thing that these trends and population growth projections definitely do indicate is that we can ill-afford to rest on our current

state of knowledge regarding agricultrural science and production. In seeking the production technologies of the future, we must focus not only on the dissemination of current research, but also on the development of new potential for increasing yields.

Following three years of extremely good harvests in the United States, and the attendant decline in grain prices, it probably seems odd to hear me call for additional investments in agricultural research designed to enhance productivity. But let's look at some wheat production figures that bear upon this statement, and as we do so keep in mind the burgeoning global demand for wheat I discussed a few moments ago.

Dr. Lloyd Evans, a noted Australian plant physiologist, has estimated the theoretical maximum potential yield for wheat at about 20 tons per hectare (some 297 bushels per acre). This theoretical maximum is based on growing the ideal variety under optimum radiation and agronomy, with no limitations of moisture, soil fertility and no crop pests. The record yield so far obtained in a farmer's field was set in the early 1960s in the State of Washington at 14.5 tons per hectare, some 73 percent of Evans' theoretical maximum. Of course, it should not be implied that achieving maximum yields would be economic for farmers, or that these yields are a realistic production objective, even for the best of farmers. Perhaps a more relevant number to ponder in the context of maximum yields is the difference between the record yield of 14.5 tons per hectare and the average U.S. yield of 2.3 tons. Even though the record wheat yield obtained in Washington State may not have been the result of an "economic" operation, the fact that average yields in the United States are only about 16 percent of the record would indicate that there is considerable room for improvement in the United States. Similar yield discrepancies exist for other developed wheat-producing countries, and in the developing world, the average wheat yield is only 9 percent of the record. If the big Third World producers (India, Pakistan, Argentina, Turkey and China) are removed from the equation, this 91 percent gap between the world record yield and average developing country yields becomes even larger!

Now, for a number of reasons, I believe that a significant portion of investments made to improve agricultural productivity should be directed toward the developing world. In the United States and other developed wheat-producing countries, much can be done to improve average wheat yields by more extensive distribution of current technologies and adoption of better farming methods. But even if production can increase significantly in wheat exporting nations, I think that most of the food needed for a still rapidly growing Third World population <u>must be</u> produced by developing countries themselves.

For one thing, agricultural imports represent an important drain on the foreign exchange earnings of developing countries, a drain that could easily become intolerable if not relieved by increased domestic production of foodstuffs, especially grain. Transport costs are another factor to consider. Ocean freight rates rose considerably between 1976 and early 1981 and, even though these rates have recently undergone a

steep decline due to excess shipping capacity caused by the world recession, they are still an important cost factor. Moreover,the infrastructure necessary to physically store and handle food imports in developing countries is already strained. It is inconceivable to me that developing countries can expand their ports and other necessary facilities at a rate anywhere near what would be required to cope with the massive increase in imports indicated by projections of current trends. Nor is it prudent for the Third World to place its food security in one or a few geographic areas.

Thus, I am convinced that proportionally more and more food production must occur in developing countries, where increased demand is greatest, as we move toward the year 2000, and to me that means more wheat production.

Third World Yield Gap

One of the most promising ways to achieve increased Third World production of wheat is to reduce the gap that exists between the maximum potential yield (given farmer circumstances) and the average yield that is actually obtained. Now, when I refer to maximum potential yield here, I'm not talking about the theoretical genetic maximum put forth by Evans. Rather, I'm talking about the optimal economic yield for the farmer, given his particular set of production conditions and constraints. The yield gap I'm referring to is the one that exists between this economic optimum yield and the average yield that is achieved in a given location or country. While the dimensions of this shortfall are predictably difficult to measure, we do have some data to work from. For the Fifth Regional Cereals Workshop, held in Algeria in 1979, a survey of the cereal production situation in a number of countries was conducted. Data returned by 15 countries showed the average yield of wheat produced by farmers, compared to experimental yields on the same farms using optimum technology.

The results are revealing: In Kenya, for example, average farm yields of bread wheat under high rainfall conditions were 56 percent of the experimental yields, a yield gap of about 44 percent. In Pakistan, average wheat yields (also under high rainfall conditions) were about 31 percent of the experimental yields, a gap of 69 percent. Under irrigation, this yield gap is even larger: about 77 percent! And in Turkey, the bread wheat yield gap under low rainfall conditions was about 63 percent, whereas under high rainfall the gap was reduced to 52 percent.

When the results from the 15 countries are averaged together, it becomes apparent that for bread wheat, only about 40 percent of the potential is being exploited, which means an average yield gap of about 60 percent. This gap is somewhat less for durum wheat and barley, but the average farm yield across environments and crops still only amounts to some 43 percent of the experimental yield: an average yield gap of about 57 percent. Reasons for this yield gap constitute a familiar litany: problems of soil infertility; poor weed control; production inputs

(especially fertilizer and herbicides) are either unavailable where needed or are too expensive; high preharvest losses to various crop pests; reductions in yield due to diseases, poor seedbed preparation and poor stand establishment; and losses of soil and residual moisture because of inappropriate tillage practices.

Resolving or reducing the Third World yield gap will require a number of approaches. Most importantly, perhaps, is the conducting of extensive on-farm research programs designed to 1) help researchers understand the existing farming systems and their inherent problems, 2) allow the testing of alternative technologies and practices under farmers' conditions, and 3) promote the development of a mix of technological recommendations appropriate to the system in which they are to be applied. Enhanced training of national crop improvement program staff and their extension service counterparts is also necessary. This training should consist of the practical, in-service type that we offer at CIMMYT, as well as advanced academic training of key personnel. In many developing countries, effective systems for distributing production inputs down to the village level have yet to be established. One spin-off that could come from on-farm research would be the design of necessary distribution systems at the farm or village level. Governments have a critical role here in assuring supplies of fertilizer, herbicides and other necessary inputs at reasonable prices.

Though hardly an easy route to follow, I see in the narrowing of this Third World yield gap a very promising avenue to increasing wheat production in developing countries. It involves the education of farmers and government personnel, and it will require additional research into workable technologies, but reducing this gap offers perhaps the best hope of making substantial near-term gains.

## Improving Genetic Yield Potential

This is not to say, however, that we should de-emphasize efforts to improve the genetic yield potential of wheat. On the contrary, past successes (some of which I'll describe here) indicate that more research is warranted, though I suspect that gradual gains are to be expected in the future, rather than the rapid increases we have enjoyed in the recent past. Let's look at a few examples of past successes, beginning right here at home.

Since 1940, U.S. wheat yields have roughly doubled, from about 16 bushels to over 34 bushels per acre in 1981, and from 1960 to 1981, yields increased by about a third. Though it is difficult to separate yield increases due to genetic gain and those due to improved farming practices, Dr. John Schmidt of the University of Nebraska reported in 1981 that average commercial yields in the late 1970s suggest we may now be entering a yield plateau with respect to genetic gains. Schmidt estimated genetic gain by comparing yield nursery data of long-time checks with new and improved varieties. He estimated that in the 1950s, improved genetic potential contributed between 8 and 20 percent to higher yields, depending on the nursery. In the 1960s, this contribution

ranged from 15 to nearly 50 percent. All nurseries showed continued yield improvements throughout the 1970s, but the estimated percentage of the yield gain due to genetic improvements declined appreciably in all nurseries. And in those nurseries where the environmental effects of droughts and cold winters are most severe, the contribution to yield by genetic improvements was nearly static. The largest yield gains due to genetic improvement were made during the mid-1960s to mid-1970s, and were most apparent in the less harsh environments.

The history of yield improvement goes back much further in the United Kingdom. England raised its wheat yields from half a ton per hectare about 1200 A.D., to one ton about 1600, to two tons about 1800, to three tons about 1940. The national average passed four tons in the 1960s, five tons in the 1970s, stood at about 5.3 tons in 1980, and 6 tons in 1982.

In a recently published report, Valerie Silvey of the National Institute of Agricultural Botany (UK) reports that the national average yields of wheat in England and Wales, rose by about 105 percent from 1947 to 1978. She estimates that 63 percent of this increase is attributable to the genetic yield potential of new varieties. During the 20 years from 1947 to 1967, varietal yields rose some 26 percent, and during the 12-year period from 1968 to 1979, the genetic component jumped by a spectacular 41 percent, over 3 percent per year.

In India, Pakistan, and more recently Bangladesh, wheat yields and production have risen dramatically due primarily to the widespread use of high-yielding varieties and appropriate production technologies. Production in India has more than tripled since 1967, increasing from about 11 million to 36.5 million tons during the same period. Similar increases have been posted in Pakistan, where production rose from some 4 million tons to over 11 million tons during the same period. In Bangladesh, production has risen from about 58,000 tons in the late 1960s to about one million tons in 1981, an amazing 17-fold increase.

These examples, and others that could be cited, point out the significant contribution that improvements in genetic yield potential have made to increasing wheat production, particularly in the last 20 years. While for the immediate future I do not foresee the kind of jump in yields that were obtained with the development and introduction of semidwarf wheats, I think most breeders would agree that through a careful juggling of genes we can obtain a slow but steady gain in yield potential. A number of approaches are open to us at this juncture:

1. We can continue to make numerous crosses within locally adapted gene pools.

2. We can probe more deeply the numerous genetic combinations possible from crossing cultivars from different gene pools. For example, a collaborative effort between Oregon State University and CIMMYT is resulting in more than 1,500 new spring x winter crosses each year.

3. We can also further explore the introduction of genetic material via resynthesized (ABD) hexaploid wheats.

4. I expect we will see important contributions to improving the genetic yield potential of wheat by making innovative wide crosses between hexaploids and related but more distant genera, such as the Elymus species.

5. Although probably not of immediate or short-run utility, genetic engineering techniques such as tissue culture may eventually have an impact on the genetic yield potential of wheat.

6. And finally, hybrid wheats are showing some promise for raising yields, especially in the developed wheat-producing countries.

## Spring X Winter Crosses

Today, most plant breeders focus their activities on making crosses either within the same or between different gene pools. Their purpose is to develop useful varieties in the shortest time possible, and these two approaches have demonstrated high rates of success given these criteria. Spring x winter crossing work is not new, but only recently have a larger number of crosses been made. Considering the past payoffs of this kind of work, and the potential benefits there for all wheat-producing countries, I think more research in this area is definitely warranted. The variety Triumph, a spring x winter cross released in Oklahoma in the 1940s, was at one time one of the most widely grown varieties in the southern Great Plains; Triumph types still occupy some 3 million acres in this region. In the late 1960s, a CIMMYT bread line, Bluebird, was crossed with Scout winter wheat. This cross eventually resulted in the winter variety, Newton, which was released in the United States in 1979 and covered more than 6 million acres in Kansas and adjoining States by 1982. CIMMYT's new Veery lines, from a Russian winter x CIMMYT spring cross, are now setting yield nursery records in many parts of the world under a wide range of growing environments. And during the 1950s, 1960s and 1970s, nearly all the varieties released and grown in Argentina were from spring x winter crosses. The Trigal 800 variety, now popular in Argentina, is from a spring x winter cross. I am convinced that many more good lines and varieties will be forthcoming from spring x winter research.

Work with spring x winter crosses has been accelerated in recent years by breeders from all over the world seeking dwarfing genes in good genetic backgrounds, those which provide for higher yield capacity, better disease resistance, improved environmental tolerance and many other traits. In particular, it is the enhanced yield capacity of the semidwarf spring x winter varieties that has attracted so much attention. At least a portion of this additional yield capacity can be explained by the apparent pleiotropic effects of dwarfing genes. Dr. Mike Gale of the Cambridge Plant Breeding Institute reported in 1982 that the Rht dwarfing genes result in the effects you see in Table 1.

Table 1. Effects of Rht dwarfing genes on agronomic traits

| Trait | Dwarfing Genes | | | | |
|---|---|---|---|---|---|
| | Rht | Rht 1 | Rht 2 | Rht 3 | Rht 8 |
| Height (cm) | 95 | -15.8 | -14.4 | -43.3 | -27.0 |
| Grain (no./ear) | 50 | +16.1% | +20.7% | +38.8% | +13.9% |
| 100 grain wt.(g) | 5.4 | - 4.1% | - 4.8% | -13.5% | - 1.7% |
| Ear yield (g) | 2.7 | +11.9% | +15.5% | +17.5% | +11.6% |
| Tillers ($m^2$) | 530 | --- | 524 | --- | --- |

As you can see, the main effects are clearly on grain yield and the yield components, especially the number of seeds per spike. The decrease in grain size reflected in the 100 grain weight is probably not a primary effect, but rather a competititve response to the increase in grain number. The higher number of grains more than compensates for the reduction in grain size. Though the data are incomplete, the number of tillers does not appear to be affected by the dwarfing genes. Most commercially grown semidwarfs that I know of have good tillering characteristics. On the negative side, it should be noted that many researchers have reported an apparent link between dwarfing genes and a reduction in protein content.

If Gale's research results are representative, and I believe they probably are, then the expanded use of semidwarf plant types represents one very important way to achieve an increase in wheat yields, at least in some of the developed countries of the world. Developing wheat-producing nations already devote most of their acreage to semidwarfs and face a different set of production constraints (as I indicated earlier). But such developed wheat-producing countries as the United Staes may have much to gain from the wider use of semidwarf varieties. In 1979, Dana Dalrymple reported in a study done for USDA/USAID that about 20 million acres, roughly 29 percent of total wheat acreage available, were devoted to semidwarfs. Today this area has undoubtedly increased; in Kansas alone the semidwarf acreage has risen by some 6 million acres since 1979. Even so, more than one-half of the U.S. wheat land could still be converted to high-yielding semidwarf varieties, and similar statements could be made about some of the other developed wheat-producing nations.

## Resynthesized Wheats

Our cultivated bread wheats (hexaploid 2n=42) combine the genetic component of three diploids, respectively. Cultivated durums (tetraploid

2n=28) were domesticated from their wild progenitor, T. dicoccoides, which evolved from an amphiploid involving two diploid wheats, T. boeoticum and T. urartu. Bread wheat originated from chromosome doubling in a hybrid between the cultivated tetraploid and the wild goat grass, Aegilops squarrosa. At each step of hybridization and chromosome doubling, only one or a few accessions of the diploids or tetraploids were involved, and the resultant polyploid was reproductively isolated immediately from its parent species. As a result, the tetraploid and hexaploid wheats received only a minor fraction of the gene pool that exists in their wild and primitive parental germplasm.

The technology to resynthesize wheat has been available since the end of World War II. There are now several resynthesized hexaploids and tetraploids available, and the opportunity is there to make hundreds more. A well-funded research program is needed to identify accessions of each parent species, to evaluate their usefulness in improving and enriching cultivated germplasm, and to resynthesize tetraploids and hexaploids for the same purpose. This research effort should also include the crossing of the re-made amphiploids with cultivated germplasm to improve the genetic background of these materials, thus making it easier for plant breeders to utilize them. CIMMYT is currently involved in such "prebreeding" work with presently available resynthesized hexaploids, but given our current funding constraints we feel we can not do an adequate job. I hope this situation will be resolved, because I think there is a great potential in the use of resynthesized wheats for the improvement of cultivated germplasm. As just one example of the potential benefits of this approach, Dhaliwal and Gill of the Punjab Agricultural University in India have indicated their belief that the excellent resistance to yellow and brown rust exhibited by wild parental germplasm can be transferred to common wheats by the resynthesizing technique.

## Wide Crosses

A fourth approach to increasing the yield potential of wheat is to transfer useful genes from related genera to wheat. The focus of this kind of wide cross work is not the improvement of genetic yield potential per se, but rather increased yields through better resistance to diseases and greater tolerance to environmental extremes. Since 1979, when Mujeeb-Kazi, an experienced cytologist, was added to our staff, CIMMYT has been giving considerable emphasis to this activity.

CIMMYT's first major involvement in wide crosses was with triticale. In more recent years, crosses of bread wheat and durum wheat were made to transfer disease resistance and other characters from one species to another. Triticale and bread wheat were also crossed, mainly in an attempt to improve the grain quality of triticale.

CIMMYT has established a number of collaborative efforts to make crosses between wheat and Agropyron, and wheat and Elymus species. In 1981, work began on crossing wheat with Aegilops species. Elymus species are being used to transfer to wheat greater tolerance to drought and salt, and resistance to leaf diseases and to head scab. Agropyron species

are known to have genes for rust resistance, salt tolerance, and barley yellow dwarf resistance. Both of these alien genera are also being screened for genes that carry resistance to fusarium (scab) and to helminthosporium diseases.

A recent scab evaluation of $BC_2$ progenies from a wheat x Agropyron cross produced some exciting results. The progenies carrying one and two Agropyron chromosomes displayed what appears to be excellent resistance to scab, a disease caused by Fusarium spp., to which there is little known resistance. Scab is an important constraint to wheat production in China, the single largest wheat producer in the Third World. As some of you know, scab was an important disease in parts of the southern Great Plains and the eastern United States soft wheat area in 1982. Scab can also be a devastating disease in northwestern Europe, Argentina, Brazil and parts of Mexico. As the production of wheat increases in the warmer, more humid subtropics, scab is likely to become a major production constraint. Consequently, CIMMYT is focusing more attention on breeding for scab resistance.

Our preliminary indicators of scab resistance in the $BC_2$ progenies of wheat x Agropyron must be thoroughly checked and verified, of course, but are promising indeed. Assuming that the alien addition chromosomes are, in fact, providing scab resistance, then it should be possible to transfer this resistance to common wheat by way of translocation techniques. These techniques for making genetic modifications for pest resistance have been successfully used by Dr. E.R. Sears and Dr. E.E. Sebesta, USDA researchers in Missouri and Oklahoma, respectively. Sears transferred leaf rust resistance from Aegilops spp. to wheat and Sebesta transferred resistance to greenbugs from rye to wheat.

## Genetic Engineering

In some scientific circles today, there is great euphoria that major production benefits will soon be forthcoming from the use of genetic engineering techniques. The new techniques in tissue culture, cell fusion, and DNA transfer are being heralded as the scientific answers to increasing the breadth, level, and stability of disease resistance, eliminating the need for conventional chemical fertilizers, and achieving major breakthroughs in raising the maximum genetic yield potential of our food crops.

Although great progress has been made by employing genetic engineering techniques with bacteria or yeasts to increase the production of insulin and interferon, there is no firm evidence at this time that similar results will be obtained with higher plants, especially polyploid species such as wheat. It is highly probable that it will be many years before these techniques can be successfully used to breed superior crop varieties. Furthermore, it is a mistake to assume that the transfer of disease and insect resistant genes into cultivated crop species through genetic engineering will result in substantially more durable resistance in subsequent varieties than we have been able to achieve to date. The ability of disease pathogens and insects to mutate into new races capable

of attacking resistant varieties is a biological reality that will continue to hound plant beeders in the years ahead.

Although some research funds should be directed toward employing genetic engineering techniques to improve breeding programs, the vast majority of research funds for crop improvement should continue to be in the realm of conventional plant breeding research. There is much that remains to be done, and that can be done, using conventional plant breeding methods to further improve disease and insect resistance, enhance tolerance to environmental extremes, and increase genetic yield potential.

## Hybrid Wheat

Hybrid wheats may hold some promise for raising future wheat yields in those countries with well-developed seed distribution networks. Hybrids with superior yield capacity have been developed and some have been recently released in the United States and Australia. These hybrids have demonstrated a substantial yield advantage over standard commercial varieties in experimental testing. Additional hybrid lines, apparently even more productive under experimental conditions, are now being extensively evaluated. Pilot and preliminary commercial-scale seed production fields are providing information needed for developing seed production and marketing procedures, but the question remains whether hybrids can be economically successful. As we gain more experience with hybrid wheats over the next three to five years, the economic viability of this approach should become clear.

## Defense of Gains

Before I conclude this presentation, there is one more point that needs to be discussed because of its bearing on the need for continued funding of agricultural research. As I mentioned only a moment ago when discussing genetic engineering, many of the natural enemies of our cultivated crops are capable of mutating and attacking previously resistant varieties. This mutational ability is an evolutionary defense mechanism that ensures the long-run survival of these organisms. Thus, these crop pathogens and pests will be with us indefinitely, which gives rise to a continually renewed threat to food production. Coping with this threat requires a substantial and continuous plant breeding effort to defend the gains in food production made in recent decades. While no plant breeder likes to think in terms of merely defending genetic improvements already achieved, the realities of pathogen/host interactions dictate that sophisticated breeding programs contain a defense-of-gains component. This kind of research is no less important than that aimed at raising genetic yield potential, and is every bit as deserving of research funds.

## Conclusion

Let me close now by leaving you with what I consider to be the primary reason for this gathering. Clearly, great strides have been made

in wheat production over the last few decades. Most of this success, both in developed and in developing countries, is the direct result of investments in agricultural science. It is also clear that wheat consumption has kept pace with our ability to produce, and that the demand for wheat and wheat products is rising at a startling rate in the Third World. While the developed wheat-exporting countries will continue to play a vital role in meeting this growing demand, wheat production in the Third World must increase as quickly as possible to help stave off widespread hunger and social unrest. The achievement of higher levels of wheat production on a global basis will require large investments in agricultural research with no guarantees of when or even whether the payoff will be forthcoming. But these investments must be made. Past successes give a clear indication of the potential contributions of agricultural scientific research. In all likelihood, however, the rapid gains in production of the past two or three decades will give way to a more steady and incremental pace. Even so, the demands of a burgeoning world population for increasing amounts of food make all advances in food production imperative. Despite the production challenges that lie ahead, I remain both convinced and hopeful; convinced that agricultural science can help us meet our future food production needs, and hopeful that the large, long-term investments necessary for agricultural science to bear fruit will be made by those institutions and governments who are aware of their absolute necessity.

# THE FEDERAL BUDGET PROCESS: WHO PULLS THE PURSE STRINGS AND WHAT DOES IT MEAN?

Dale L. Stansbury
Director, Food and Agricultural Programs
National Association of State Universities and Land-Grant Colleges
Washington, D. C.

The Federal budget process is determined by the Constitution, the Budget and Accounting Act of 1921 and the Congressional Budget and Impoundment Act of 1974. Article I, Section 9 of the Constitution states "No money shall be drawn from the Treasury, but in consequence of appropriations made by law." The basic requirement of Federal budgets is the Congress appropriate the money. However, this is the final step. The critical question is how do we get to the appropriations point.

The Budget and Accounting Act of 1921 establishes the procedures for development of an "Executive Budget." Prior to this time, individual agencies and departments worked directly with appropriations committees and there was no unified Federal budget. The Act requires a consolidated Federal budget which the President submits to Congress.

The other major budget act is the Congressional Budget and Impoundment Control Act of 1974. This Act primarily deals with how the Congress shall conduct its budgetary process and since passed, Congress has tried to deal with the total budget.

These constitutional and legislative mandates are not discrete entities. While they tend to be sequential, there is a high level of interaction at nearly every stage. The process is approximately three years from initial development through expenditures. The first "year" is the Executive budget development period. The second "year" is the Congressional review and appropriations period. "Year" three is the expenditure period. The result of this is there are three fiscal year budgets of concern at any given time and frequently four. For instance, we are in fiscal year 1983. However, the spending level is determined by a continuing resolution based on fiscal 1982 as we wait final action by the Congress on the 1983 appropriations bill. Fiscal 1984 is currently in OMB being finalized for Presidential submission to the Congress in January. The first planning sessions for fiscal 1985 with regard to the program levels are already started in the Executive branch and by the people such as experiment station directors who are actively involved in the programs funded by the Federal budget.

## The Executive Budget Process

It is within the Executive budget process that each new budget is born. The Budget and Accounting Act of 1921 governs the process. This Act requires that all budget requests be consolidated into a single budget request for presentation to the Congress by the President. The process begins about two years before the actual expenditure. In fact, ARS scientists have already begun the budget planning process at the program level for fiscal 1985 which

runs from October 1, 1984, to September 30, 1985. This represents the first stage in the Executive budget process and will proceed over the next five to six months. At the second stage, the agency administrators begin consolidating the wish lists of project and program leaders and begin to make funding recommendations for various research projects and programs. This period between March and July or about a year and a half before actual expenditure is when the reality of budget development begins. The wish lists are subjected to the first of a series of adjustments, cuts, and tradeoffs. At this point, there is still a level of homogeneity--that is, wheat research versus other agricultural research; however, conflict is the name of the game from this point forward.

Stage three is the period from July to mid-September when the Department of Agriculture budget is developed. Here the budget process brings the divergent interests of the Department together. The competition for funding now includes soil conservation, food stamps, animal welfare, and every other program of USDA.

Stage four begins on September 15 when the Department submits its proposed budget to OMB. Now the budgetary competition for agricultural research includes all other Federal programs, agencies, and departments. In OMB, specialized budget examiners review Departmental submissions. They conduct hearings with Department and agency representatives. The Department budgets and the budget examiners' recommendations are subsequently consolidated into a preliminary OMB budget. This budget is given to the Department for comment and appeal if the Department desires. The appeal process begins with OMB but it can go all the way to the President if there is not satisfaction between OMB and the Department officials.

The final stage is reached when the President makes the final decisions on the Executive budget which is to be submitted to Congress 15 days after they convene--typically the latter part of January or early February.

## The Congressional Budget Process

Receipt by Congress of the Executive budget effectively begins the Congressional budget process. The principal actors are the appropriations and budget committees. Legislative committees such as the Senate Committee on Agriculture, Nutrition, and Forestry provide legislative authority for appropriations. However, these authorizations are usually intact and it is the appropriations committees that determine the level of fundings of programs.

The sequence of events is determined by the Congressional Budget and Impoundment Control Act of 1974 as follows: In January, Congress receives the Presidential budget. Between receipt and March 15, the legislative and appropriations committees file their views with the budget committees with regard to the budgetary priorities, needs, and allocations for the programs under their jurisdiction. Between March 15 and May 15, the Budget Committee of Congress works on the first concurrent resolution for the budget. The first concurrent resolution is a budget guideline that sets out targets by functional areas which are designated by numbers. Agriculture research is included in the

350 budget function. These functional areas in the budget resolution are rounded off at 100 million dollars. The Congressional Budget Act requires that all of the appropriations bills be enacted before September 15.By September 15, a second concurrent resolution is to be passed to take account of adjustments needed due to appropriations acts or new legislative activities not included in the first concurrent resolution. The final step occurs where the second budget resolution disagrees with appropriated funds in the 13 appropriations bills. In such cases, there is a process known as reconciliation. The law requires reconciliation to occur by September 25. The new fiscal year begins on October 1 with total organization and certainty.

So much for theory. In fact, the process seldom follows the format laid out here. In the 1982 budget, there was reconciliation after the first resolution rather than the second. In that case, the first resolution became a mandated legislative program rather than a budget target program. Significant debate has occurred over the past couple of years about the appropriateness of this course. Increased numbers of skirmishes have occurred between the appropriations committees and the budget committees about the budget process and between authorizing committees and budget committees about defacto legislative action in the budget process. It has become a partisan exercise which some people suggest has resulted in a total breakdown of the process.

Thus, the government is functioning today on a continuing resolution into the new fiscal year without budget resolution, reconciliation, or appropriations. However, it is functioning.

## Year Three: Obligations and Expenditures

This is the fun year. In spite of the apparent confusion and uncertainty of the process there are ways to provide for funding as required in the constitution. Thus, obligations and outlays for programs do take place without the concurrent resolution or appropriations acts. The unique issues in this period are the provisions for appropriations adjustments. These adjustments include supplementals, recisions, and deferrals. The supplemental appropriation is a fairly straight forward concept of adding money in the year of expenditure. However, its use tends to be limited to nondiscretionary programs such as entitlements or legislated salary adjustments. A recision is a Presidential request to withdraw funding from a program while a deferral is a situation where the President proposes that funding activities be postponed. Affirmative action by both houses is needed for these adjustments under the Congressional Budget Act.

The outlay year begins at the same time the cycle for the budget development for the fiscal year two years away also begins again, so the cycle continues and as noted there are always three budgets pending.

## Budget Development Actors

The budget development process is broken into two distinct periods--the Executive and Congressional. However, within these two are numerous unique actors and focuses. At the program level of the Executive period, the actors

are those who know the most about the specific issues, for example wheat researchers focus on wheat research programs. They are making their wish list of what would be ideal. Between May and July adjustments start to be made under budgetary limitations handed down to the agencies by OMB. Research administrators must decide between the ideal amounts for each program and the best package of programs for the agency. It still tends to be a budget made up of generally similar programs such as agricultural research.

At the Department level the adjustments are made among dissimilar programs. At this juncture the Soil Conservation Service, the Statistical Research Service, the research activities of ARS and CSRS become competitors. It is not a one on one competition, however, the need to maintain a fiscal balance means no program can function independently. The Executive budget reaches the fourth step when it goes to OMB. Here, the Department of Agriculture faces the Department of Defense, and the Department of Health and Human Services as it competes with other Departments to capture the maximum number of dollars possible for its most important programs. In all cases, each Department is convinced that its programs are the most important. The final decisions in this process are made in the President's office. With the biases of any President and his immediate advisors, shifts can occur in favor of or against any Department, agency or program.

Agricultural research has done very well through most of this process recently. Agency and Departmental support have been high, particularly for the last few years. Secretary Block, Deputy Secretary Lyng, and Science and Education Administrator Bertrand have all been active supporters of the agricultural research and extension functions. They have fought hard at the OMB level and appeals all the way to the President's office have occurred. They have won significant adjustments in the process. These efforts and successes suggest that a relatively good environment exists in the Department and at the White House for agricultural research.

In the Congressional period, the main budget actors are the appropriations committees although the authorizing committees do set the stage. Because the budget committees tend to deal with macro budget issues and budgetary amounts greater than a hundred million dollars, many activities in the programs of agricultural research don't show up in their budgeting process. Support in Congress for agricultural research has been outstanding, especially during the periods of rather negative attitude in the Executive branch.

This takes us to the points of influence and where we can have an effect on the budget process. In the Executive branch input at the program level is easy. Researchers in given fields at the university, in industry, and at the Department of Agriculture are in fairly close communication. They all agree their research is where research money should go. However, the relative importance of the program level is at best of medium level of importance in budgeting. The critical issue at this level is inclusion because projects not included at the program level seldom show up in final budgets. However, the process is a long one before final appropriations with most adjustments from this point on being reductions.

Agency input is also a fairly easy point of access. Experiment station directors and industry representatives are able to communicate with the administrators of the Agricultural Research Service and the Cooperative State Research Service. They can communicate with the Assistant Secretary of Science and Education and frequently are members of Advisory Committees including the Joint Council. The importance here is high because these are the people who make the critical decisions about the research package that will go forward in the Department. They are the people who develop the budget notes that support the proposals. This level is critical because it is the last point of public input in the executive process.

Input at the department level is limited. The budget goes behind a curtain at this point and only Federal employees can work on the budget. This is a critical period of the budget process and good representation at policy level of the Department is important. Here is where State cooperators and private sector people must depend on the science and education administrators of USDA.

OMB is also a very difficult place to have an influence. OMB staffmembers frequently refer to themselves as the "no" agency. Their importance is very high. However, there is a hearings and appeals process where people in the "know" participate. Over the past few years, the Department has been able to secure good support for agricultural research which suggest our "know" is better than their "no".

Within the Congress, the authorizing committees are the easiest to approach. It is very easy to reach members of the two agriculture committees and get them to say how wonderful agriculture research is and how more funds are needed. Unfortunately, the relative importance of these committees is not very high in the budget process since they don't make decisions on appropriations. The budget committees are relatively difficult to reach; however, budget committees are also relatively unimportant in the specific determination of agricultural research funding. The appropriations committees are the ones with the purse strings. There is a mixed ability to reach these committees. They tend to be open in their hearing process and are willing to listen closely to recommendations; however, much of their work is done in executive session. It should be noted, the committees have very professional and knowledgeable staffs and the committee members have been strong supporters of agricultural research.

## Conclusion

The funding provisions of authorizing legislation and appropriations for agricultural research leaves most of the decisions about what research and how the research should be done to research administrators in ARS and at the experiment stations. Very little of our agricultural research is dictated in a narrow sense of focus or disposition. There are always some special programs that are specified by Congress. These tend to have close correlation with the membership of the appropriations committees. But on the whole, the important thing is to develop and build a research budget adequate to meet the priority research needs of agriculture. The decision of how much wheat research and what types of wheat research are questions the wheat industry should address with research administrators at the experiment stations and at USDA.

You are in competition with other agricultural groups who want research on their products whether it be soybeans, forestry products, or livestock. However, to the greatest extent possible, specific interest groups in agriculture should try to keep their debates about research priorities as far away from the political process as possible. The debate between wheat and soybeans research priorities can be better addressed at the research level than it can at the Congressional level. If agricultural groups start making charges and countercharges against one another in a Congressional hearing or at an OMB hearing the result is probably going to be a long-term loss for all agricultural research. Agriculture has a limited political base. To assure the adequacy of the overall agricultural research program, it is important to hold together in the budget process.

# WHAT'S AHEAD FOR THE AGRICULTURAL RESEARCH SERVICE

T. B. Kinney, Jr.
Administrator, Agricultural Research Service
U.S. Department of Agriculture
Washington, D.C.

This first National Wheat Conference brings together distinguished representatives of the National Association of Wheat Growers, scientists from State and industry, and representatives of the Agricultural Research Service. I hope that these proceedings will promote a free and open exchange of ideas, as you address an exciting and demanding agenda.

I'm delighted to have the opportunity to share some thoughts with you about what's ahead for ARS in the area of wheat research.

We are fortunate to have a Secretary of Agriculture who is very outspoken in his support for agricultural research as an investment in America's future. He has emphasized many times in speeches that we need to strengthen agricultural research to sustain production capabilities, expand exports, improve marketing, and improve the management of our soil and water resources. By increasing the production and quality of our grain, we are able to build exports that help offset costs of imports--and also strengthen prices farmers receive. Secretary Block has pointed out that agricultural research provides 35 to 50 percent annual returns on tax payers' investments. Certainly, if America can eliminate inflation--and I believe we can and must--future investments in research may return even more, dollar for dollar, than they do today.

My remarks this morning will address three areas for your consideration. First, I will touch upon some of the service types of research programs conducted by ARS in the area of wheat research. Then, I will go into somewhat greater detail about our collection, maintenance, and dissemination of useful germplasm. Finally, I will have some comments about the recent studies critical of the State/Federal agricultural research system--and the ARS response to these studies.

Technology used today in the highly successful American agricultural production system is the direct result of a partnership involving ARS, the State Agricultural Experiment Stations, and American industry. No one group alone could even approach the contribution made by this troika.

Most research conducted by ARS is of a national or regional nature, and in the future we will be even more oriented in that direction. The ARS germplasm program is a good example.

I think most would agree that the Federal sector has an emerging responsibility to discover and store germplasm, and to appraise its potential. We also have the responsibility to develop genetic lines to make them available to breeders.

As a Federal Agency, ARS can more effectively collect germplasm on a national and international scale and test accessions anywhere in the United States where climate, soil, or other conditions are the best available for measuring a particular attribute. ARS is better suited to conduct this type of operation, and then disseminate germplasm lines domestically or internationally, than any one State Agricultural Experiment Station. An industry involved in wheat breeding cannot afford to gather and maintain its own germplasm material.

ARS conducts several additional "service" type research programs which have national significance and national impact. I will discuss four of these programs.

First, let's take a look at the Regional Uniform Wheat Performance Nursery Programs. There are four wheat production areas in the United States: the Great Plains Winter Wheat Region (Central and Southern Plains States); the Great Plains Spring Wheat Region (Northern Plains States); Eastern Wheat Region (essentially those States East of the Mississippi River); and the Western Wheat Region.

ARS conducts one or more test nurseries within each of the four Regions. Virtually all of the public agency advanced wheat breeding lines that are considered potential varieties, and some from industry, are given their final test for yield, disease reactions, and quality in this nursery series. ARS has maintained the Regional Uniform Wheat Performance Nursery Testing Program for more than 40 years. This system is an integral part of the entire research effort directed toward wheat improvement in the United States. The system benefits all three partners involved--the State Agricultural Experiment Stations, ARS, and private industry.

Another part of the wheat evaluation program is the quality testing conducted by ARS at four regional wheat quality laboratories. These laboratories are located at Manhattan, Kansas; Fargo, North Dakota; Wooster, Ohio; and Pullman, Washington. Each laboratory serves in a quasi-regulatory role by evaluating the potential varieties tested in the Uniform Wheat Performance Nursery Programs.

In these wheat quality laboratories, a final test for milling and baking quality is performed on each potential variety for all public agencies. All results from quality and field performance tests are made available to cooperators in the regional programs. In this way, wheat varieties of tomorrow are chosen on the basis of their agronomic and quality performance.

The third service research program is located in the Cereal Rust Laboratory at St. Paul, Minnesota. Stem rust is potentially the most damaging disease of wheat in the north-central plains. The Cereal Rust Laboratory has played a major role in holding stem rust in check over the past 25 years. During that time, there has not been a major epidemic in the United States--an unmatched accomplishment in the history of wheat growing in the United States.

The laboratory staff coordinates the annual monitoring and identification of stem rust races found in the United States, and uses those plus other races to assess various sources of resistance to them. This has permitted research scientists to develop superior wheat varieties, often with multiple resistance to stem rust.

Continuing evolution of new races of the stem rust fungus requires constant vigilance on the part of researchers. They must monitor the pathogen population every year to detect any changes, and they must constantly screen new germplasm and search for new resistance genes to assure protection against future rust epidemics. Even though stem rust is presently under control, the situation could change quickly. Cereal Rust Laboratory personnel are involved with research on other rust species also.

The fourth service program, the International Wheat Rust Nurseries, was initiated in 1950, and is coordinated by ARS from Beltsville. New and promising experimental lines of wheat, germplasm, and even wild species related to wheat are tested worldwide to the natural populations of rust. Through these wheat rust nurseries, we hope to monitor the rust populations all over the world, keeping track of race shifts, and identify sources of resistance to rust. The data are collected on three rusts parasitic on wheat--stem rust, leaf rust, and stripe rust.

Now, let's take a few minutes to consider germplasm. No single research activity can be more important to the future of wheat--or other agricultural commodities--than the collection, maintenance, and dissemination of useful germplasm.

It is absolutely necessary for the research scientists, particularly the breeder or geneticist, to have a broad germplasm base upon which to draw as a source of genetic traits. Genetic diversity is the basic working tool of the agricultural scientist who wishes to design a better variety. Genetic diversity is an absolute requisite for genetic advance.

A major need in our wheat germplasm program is to adequately evaluate the 37 thousand accessions now held in temporary quarters here at Beltsville. And, we must systematically evaluate new material that comes into this collection every year.

ARS makes each and every accession available to plant breeders and other research personnel upon request. Germplasm can be much more valuable to the user if the collection can respond to specific needs. For example, if a request is for the best resistance available to TCK smut, we want to be able to provide elite lines of wheat which possess the most effective genes for dwarf smut resistance that are available. At present, some accessions are described for some characters. We are gearing up now to begin the very necessary systematic evaluation procedures.

Germplasm improvement, otherwise known as germplasm enhancement, is another highly important research function for ARS. Most introductions into the wheat collection are in the form of "raw" germplasm. These wheats most likely would not excite the wheat growers in this audience. More than likely, the wheat lines would lodge badly (have weak straw), be poor yielders, perhaps would shatter their seed, and probably would make a poor loaf of bread or an uninspired cookie.

In spite of such shortfalls, one or more of these lines may have extremely useful and unique characteristics, such as a highly effective gene for stem rust resistance. The task for our wheat breeders and geneticists is to improve or "enhance" that germplasm, by transferring that gene for stem rust resistance into a better genetic background. With this procedure, the improved line would have at least halfway decent straw strength, would not shatter or lose its seed before harvest, would have at least satisfactory quality, and, most important, would provide the user with very good stem rust resistance in a much improved genetic background. This improved germplasm line would still not be a finished wheat variety; but it would be a long way from the original raw germplasm. The improved germplasm lines would be made available to any bona fide plant breeder, or other research scientist, to be used toward further wheat improvement.

Now, I am going to comment briefly upon the mission of ARS and the special capabilities of this organization as a part of the national agricultural research complex.

The Agricultural Research Service is the USDA's principal intramural research agency. The mission of ARS is to plan, develop, implement, and evaluate research that is designed to produce the new knowledge and technologies necessary to ensure the continuing vitality of the Nation's food and agricultural enterprise. As a Federal research agency, ARS addresses problems that are of national concern. We conduct research and development that are appropriate for the Federal Government, and we make use of the unique capabilities of ARS scientists and the facilities in which they work--a combination that forms an integrated and coordinated national resource that is not duplicated by others in the U.S. agricultural research community.

ARS has scientific capabilities comprised of more than 2,700 scientists and engineers plus support staff with the knowledge, technical expertise, and specialized scientific equipment to respond to broad regional and national problems. ARS operates unique facilities and laboratories which provide essentially all the disciplines demanded by agricultural research. Many of the facilities are highly specialized. For example, we operate laboratories for the study of exotic diseases of plants and animals. Facilities are located strategically across the major farm and range land ecosystems and climatic zones of the United States and eight foreign countries. And some, such as the Agricultural Research Center here at Beltsville, the world's largest center, are recognized both here and abroad as excellent, multidisciplinary research facilities.

So, I submit to you, that the Agricultural Research Service is basic to the future success of American agriculture. The work of this agency has been basic to the success of American agriculture for decades. We have every reason to assume that the importance of the work ARS carries out will increase, if anything, because of the importance of Amnerican agricultural exports in the world market.

And, ARS is basic to the success of American agriculture because we have the facilities and the expertise to address the research challenges in a unique way. Because of our Congressional mandate, we must pursue basic, long-range, high-tech research affecting national or regional agricultural concerns. This is research that cannot or will not be carried out by the States or by the private sector.

Basic research warrants governemnt support because it is an investment in the future--in a better quality of life, better security, a better economy, and simply better understanding.

Having described our mission, I must also acknowledge that ARS has some serious problems. Over the recent past, this agency has been the subject of a number of critical studies. Let me identify some of these studies and comment upon their recommendations.

In July 1981, the General Accounting Office (GAO) submitted a study which concluded that the U.S. agricultural R & D system does not perform national long-range planning, and that the USDA/State programs are independently planned. In response to this report and similar recommendations from other sources, the Agricultural Research Service has initiated the most significant strategic planning activity in the Agency's history. I will have more to say about our strategic plan with regard to wheat research later in these remarks.

The GAO Study recommended an inventory of the Small Grains Collection, and this task was begun one year ago. The GAO recommended verification of the need for germination testing equipment at all facilities, and the conclusion was reached that seed germination testing can be most effectively accomplished by centralized responsibility. The study recommended that ARS determine the extent curators are behind in their germplasm grow-out programs; the situation is being reviewed and priorities will be established for grow-out programs.

The Office of Technology Assessment submitted a study in December 1981. The OTA study noted that the USDA research expenditures are proportionately the smallest of any major Federal research agency. In 1978, USDA's share of Federal expenditures for R & D was 1.5 percent of total expenditures compared with Defense (45 percent), Department of Energy (16 percent), and Department of Health and Human Services (12 percent). This Administration has given strong support to research and extension in each of its budget requests. The OTA study noted that there is confusion over roles and lack of coordination by research participants--and there certainly is always room for improvement in this area.

The Winrock Conference, held earlier this year, provided a summary of key issues confronting the agricultural research community. The Conference noted that many reasons have "greatly exacerbated national institutional resistance to change, resulting in excessive parochialism and preoccupation with institutional protection and maintenance." The Conference went on to point out that inadequate attention has been given to identification of critical research needs or the development of institutional relationships to bring about needed changes.

Earlier this year, the Users Advisory Board and the Office of Management and Budget presented reports and studies critical of certain aspects of research management, and responses to these recommendations are being prepared.

Of the ARS scientific staff, 77 percent is 40 years of age or older. That figure implies that turnover and loss of experience will be extensive during the next few years. We also face a shortage of young, recently trained engineers, computer scientists, biophysicists, molecular biologists, and other critical specialists in the rapidly evolving disciplines needed to solve problems of the future.

The current ARS budget of about 450 million dollars annually has approximately the same purchasing power as the 1966 budget. Clearly, there are limits to the kinds and numbers of problems that can be undertaken within 1966 budget levels. Hard choices must be made.

The Agricultural Research Service must maintain a research climate that attracts and retains the best scientists and thinkers in order to fulfill the Federal commitment of delivering the science and technology that is essential to meet continuing, long-term needs of agriculture.

So, very briefly, I have described some of the criticisms leveled at the Agricutural Research Service and the Federal/State/private agricultural research system. Clearly, the manner and the tone and quality of our response to these criticisms may, in large part, dictate our future.

Many of our critics control our resources. For me, as an Administrator, or for anyone working in ARS, to presume that we can ignore these comments is to dictate failure in the future.

In my opinion, ARS is the finest agricultural research organization in the world. Since 1953, when the Agency was created, we have been highly productive and responsive to the needs of America's agricultural industry. Over the past three decades, we have played a leading role in the agricultural research and production system of this country.

Therefore, I am not willing to accept criticisms about the quality and appropriateness of ARS research--when these criticisms are not deserved. I will accept recommendations for improvement--recommendations about how we must meet the challenges of the future.

It is my intention to address each of the criticisms and recommendations as rapidly as possible in a positive and complete manner. I only make one plea. We have had more than enough studies, criticisms, recommendations and controversy to last a long time. Please give us a chance to respond to what has been said up to now about America's agricultural research system.

We must address our critics. If they are wrong, we will tell them why they are wrong. If they are right, we'll respond, and we'll respond rapidly.

We have already begun to respond.

We are presently in the process of developing a strategic plan to achieve the ARS mission and goals. This strategic plan identifies and explains the main problems that confront the agricultural industry and charts the minimum courses of action that will provide the research needed for solutions. This plan is being developed under the leadership of the National Program Staff with input from more than 500 ARS scientists and in consultation with colleagues from the universities and industry.

Now, I would like to turn to that portion of the strategic plan that concerns wheat research. The research thrusts or research areas of high priority for the future--1990 and beyond--include in approximate priority order the following six areas.

1. Collection, evaluation, preservation and distribution of wheat germplasm--what is now in the collection and new germplasm being added each year.

2. Development of new methods of modifying or improving wheat germplasm. Various aspects of genetic engineering, such as cell and tissue culture, recombinant DNA techniques, and similar new tools can help the scientists improve wheat germplasm. Such tools can greatly speed improvement--but they will not replace tried and true plant breeding procedures which have been used so successfully. New breeding methods deserve considerable attention in the next decade.

3. Improvement of genetic populations of wheat. This includes the actual improvement or enhancement of germplasm of wheat, which will be a very important part of our research effort in the future. ARS scientists likely will be less active in the final stages of wheat varieties, but they will concentrate their efforts on converting "raw" germplasm into much more useful genetic material.

4. Development of knowledge concerning basic plant growth and development processes. Such basic research would enable the plant breeder and other scientists to better understand photosynthesis, nitrogen uptake by the wheat plant, and why some plants are more winterhardy or drought tolerant than others. With this type of knowledge, the research scientists can do a better job of manipulating the wheat plant's genetic system, so that a more desirable wheat variety can be engineered.

5. Development of knowledge of how a wheat plant can resist (or at least tolerate) the attacks of diseases and insects. Pest resistance has so far been the most effective way to protect plants from pests, and very likely will continue to provide the best protection. The more a scientist understands such means of protection, the better the job can be done toward wheat improvement.

6. Development of basic principles of cultural and management practices, so that better farming systems can be introduced.

What's ahead for ARS? There isn't anything dramatically wrong with ARS. We are simply preparing for a move into the future.

In this move, we are putting our resources behind our rhetoric. In other words, we are putting our resources where our mouth is.

The strategic plan may call for some actions that will cause personal hardships for some people. It's going to, on occasion, require scientists to relocate and change the direction of their careers. I am not talking about realigning boxes and titles. I am talking about a serious realignment of programs, talent and resources.

These are dynamic and challenging times. I am confident that with your cooperation, the future of the Agricutural Research Service will be as brilliant as its past.

# THE FEDERAL BUDGET PROCESS AND RESEARCH PLANNING; STATE AGRICULTURAL EXPERIMENT STATIONS

Raymond J. Miller
Dean and Director, College of Agriculture,
University of Idaho, Moscow, Idaho

The agriculture research and extension budget process is very detailed. This is necessary because of the importance of the undertaking and because of the number of people and different groups involved. First, I'd like to give you a glimpse of the budget process and how you can affect it. Second, I'd like to give an example as to how more of the science and education efforts are going to need to be planned and coordinated in the future.

## State Agricultural Experiment Stations Budgets

The budgets or financial resources of most SAES are made up of four major sources:

1. State appropriations
2. Federal formula funds - USDA approximately 20%
3. Local income
4. Grants and contracts

Wheat growers can impact three of these sources. State appropriations are usually the largest single source of funds for agriculture research and can be impacted by your state organization. Yet, too often this source is ignored. You can and should let your State senators and representatives know how important science and education are. Grants and contracts are impacted by your commodity funding grants and by line items in the Federal appropriation. You should also be heard as to the importance of formula funds as they are part of our base budget.

## The USDA - Science and Education Budget Process

The USDA Science and Education budget process is long and detailed, three (3) budgets are usually in process at any one time. For example, we are now in fiscal year 1983. The FY 84 budget has been prepared and submitted to OMB. The FY 85 budget preparation has started. We will briefly review the budget process.

The USDA Science and Education is composed of four agencies: Agricultural Research Service; Cooperative State Research Service; Federal Extension; and the National Agriculture Library.

The CSRS is the Federal agency that works with and represents the State Agricultural Experiment Station within USDA. Federal Extension works with and represents the State Cooperative Extension Service within USDA. Both agencies are responsible for the formula funds that come to the States through USDA.

This formula includes factors such as rural and urban populations, number of farms, etc. The ARS is the inhouse research organization and the NAL is the national library of agricultural material.

In the CSRS budget there are three major components of interest to wheat growers: Hatch-formula funds; competitive grants; and special grants.

Formula funds are part of the base funds of the SAES and are usually used to hire the scientists, operate the experiment stations, etc. Competitive grants are used to support more basic research and are awarded on a competitive scientific basis. These are only used for pre-identified areas and include N-fixation and genetic engineering. Special grants are line items specifying a specific number of dollars for an identified need and may include where the work is to be done; such as TCK smut in the Northwest. Growers can particularly impact the formula and special grants lines.

The budget planning process starts very early.

1. Priority establishment by State, regions, joint council and other groups. Input to budget committee.
2. Problems and need identification of budget committee and CSRS staff - August-September.
3. Preliminary identification of needs and priorities - October-November.
4. National needs identification of S & E agencies - November-January.
5. S & E + Division Agriculture budget committee meetings and budget preparation - December-May.
6. S & E - final budget preparation May-August
7. USDA hearings and final budget preparation - August-September
8. USDA - OMB - September
9. OMB - USDA - October-November
10. Negotiations - OMB - USDA
11. Presidential budget presentation - January-February
12. Budget committees in Senate and House. Recommendation.

Where can wheat growers impact the process? At the State level, No. 1, make sure your directors of SAES are fully aware of the problems and needs so these needs can be put into the priority process. The final budget preparation for S & E, No. 6, and USDA hearings, No. 7 are important for impact, but particularly before 7 you should make sure people in USDA understand how important S & E is. And then through Congress at the budget committees, again make sure the membership knows your problems and needs, and the importance of S & E.

Budget preparation is continuous; spending one, negotiating the second, and preparing of the third. Your input and needs are important at the SAES, State and National level. Be heard, particularly by the legislators. We're responsive but priorities are necessary and there are not resources to do everything.

Cereal Research

Wheat research and cereal research in general have many needs; more resistant varieties, pest control, management, erosion control and many more. All of these cannot and will not be done in all the areas where we'd like them to be done. In addition, we have to be developing new technology for the future such as N-fixation for nonsymbiotic plants, that is, nonlegumes, or genetic engineering for the transfer of cells from one organism to another. This technology is not here yet but it is coming fast and we must be prepared to use it.

What do we do with all of these needs and limited resources? First, we must have the best possible communication; we must get involved both financially and personally by interaction; priorities must be set; we must realize that all things can't be done, but most of all, we must develop many more jointly planned, developed, and implemented S & E programs than we have now. These must be across State and agency lines and must involve scientists of many disciplines, producers, user agencies, and other interested people.

STEEP as a model (Solutions To Economics and Environmental Problems)

There are many multidisciplinary programs, but few that involve so many scientists, that cover so much geographic area, or that have been initiated by the growers as the STEEP program. This project will be explained in more detail by other speakers. But here are some of the most important features for initiating such an undertaking.

First the general problem area has to be identified such as maintaining or increasing wheat yields and reducing erosion. Then it is necessary to:

1. Identify the specific problems
2. Determine what needs to be done
3. Define what is being done
4. Specify what we need to do - in priority order
5. Who is going to do what - including resources
6. Develop a coordinating and continuous planning system.

This is an example of what was done in the STEEP program. Five major objectives were identified. These were and are: a) Tillage and plant management; b) Plant design; c) Erosion and runoff prediction; d) Pest management; e) Economics of erosion control.

Then the other steps listed above (1-5) were followed for each objective and a coordination/planning system was developed (6). A steering committee composed of five scientists who have expertise in the five objective areas were selected and they also represent the three States involved - Oregon, Idaho, and Washington as well as ARS. This committee works with the scientists, the growers, and the administrators to provide overall direction to the program.

To make such efforts work, all people involved must be communicative, adaptable, and willing to adjust to changes. There must also be a system for organizing the effort.

## Summary

The budget process is a complicated and continuing process but you can and should be involved and have impact. Funds for S & E will continue to be scarce so the result will be an even greater need for priorities and multidisciplinary research. We can and will establish priorities, but these priorities in some cases will require more adaptive approaches on our part, and above all, less procrastination by all of us.

Agriculture is the major and most fundamental industry of any nation. It has been the stabilizer in the United States, but agriculture must become more efficient. I do not mean produce more in total, I mean we must be able to produce more per acre, or per cow, at the same cost. Without increasing efficiency we will not keep American agriculture competitive and we won't hold our place in the international markets.

The only way there will be increased efficiency is to have a strong science and education system to provide the new technology needed and to have the trained people to use that technology. It's your future, you must be involved in the problem, the priority, and the financing of the science and education effort.

STATE WHEAT COMMISSIONS

Merle Hedland, Executive Director
Minnesota Wheat Research and Promotion Council
Red Lake Falls, Minnesota

It is a pleasure for me to be here today to present a brief statement on behalf of the states that currently administer per-bushel check-off programs for wheat. My figures on the dollars spent on wheat research, and specifically, on the various types of wheat research, are fairly accurate. They are based on reports from the various states. The totals are skewed a bit because the report from Montana included a check-off for barley, which is also administered by the Montana Wheat Research and Marketing Committee. Wyoming also has a penny check-off program, but since their production is relatively small, and since most of their funds are allocated to the market development program through U.S. Wheat Associates, their figures are not included in either the total revenue or in the research data. With these minor exceptions, the picture that I will attempt to paint will be relatively vivid as to the role these producer directed and supported organizations play in the total wheat research picture. Despite the validity of the numbers, the opinions that I will express at the end of my remarks are my own and may provoke argument among my colleagues who handle the day-to-day activities of the various Commissions, Councils, Committees, or Boards.

For the record, there are currently thirteen wheat check-off states and other states are considering implementing such programs as well. The states that currently have programs include Colorado, Idaho, Kansas, Minnesota, Montana, Nebraska, North Dakota, Oklahoma, Oregon, South Dakota, Texas, Washington, and Wyoming. These represent the bulk of production for Hard Red Winter Wheat, Hard Red Spring Wheat, White Wheat, and Durum. Soft Red Wheat, however, is noticeably absent. California is planning to hold a referendum after the first of the year to institute a wheat check-off and Arkansas is also considering such a move. No other states are currently considering a check-off for wheat but I believe that Jerry Rees of the National Association of Wheat Growers and Winston Wilson of U.S. Wheat Associates are targeting other states for future development.

The check-off levels vary from state to state, ranging from a low of three mills, or three-tenths of one cent, per bushel, to an envious high of two cents per bushel. This generated revenues ranging during the 1981-82 fiscal year from a low of $200,000 to a high of one and one-quarter million dollars for a total collection of about 9.6 million dollars. For the most part, the check-off levels are fixed amounts that can only be adjusted through state legislative action or by producer referendum. However, one state has a provision that calls for a check-off of one-quarter of one percent of the market value to the producer. This is a good hedge against inflation, but it must make life a little difficult during this period of desperately low prices.

It should be noted that a number of states are currenlty undertaking programs to increase the levels of check-off and others are hoping to do so in a year or two. As these levels increase, or as new states are brought in, total revenues will increase accordingly.

Wheat research during the 1981-82 year totaled $2 million or 21 percent of the total dollars collected through the check-off program (see attachment #1). State-by-state percentages ranged from a low of 5.7 percent to a high of 36.7 percent. The balance of the fund, I would have to estimate, because I did not include the questions on the form I sent to each state, would be allocated roughly 25 percent or less for administrative costs and 54 percent or more into the broad category of promotion or marketing, which could also include an information program.

By type of research, the development of new varieties and agronomic practices, on the average, receives the largest share of the funds, receiving $646,000 and $626,000, respectively. These represent 31.8% and 30.8% of the total research dollars. Disease control was allocated 15.3%, wheat quality 11.5%, transportation 3.5%, marketing 2.5%, and other research 4.2%. Although $2 million dollars seems like a lot of money, in general, it represents a relatively small amount of money spent on wheat research in the various states. In Minnesota, the Wheat Council's contribution to the University of Minnesota represents only about 15 percent of total receipts from state sources. One state wheat organization contributes 29 percent of the total, but on balance, the check-off funded percentage, as compared with the total wheat research dollars, is relatively small. Despite its small size, however, the wheat check-off grants are important. For Minnesota, Dr. Bob Busch, who is a participant on this program, reports that the Wheat Council grants have allowed him to increase the wheat breeding program by 50 percent, particularly in the early generation materials. In effect, once the base research program and personnel are in place, through state and federal funding, the check-off money can be used almost totally for research programs, with only limited amounts for overhead. It is a little cream on the top, so to speak. An example would be to have a $70,000 tractor that will only function when you put in a few dollars worth of fuel.

The $2 million and 21 percent of check-off funds allocated to research is, as of today; the future remains somewhat clouded. The almost three-to-one ratio of dollars spent on market development versus dollars for research, is a signal as to what may lie ahead.

The market development program, the expansion of export and domestic markets for farm products would, without a doubt, carry the highest priority by all wheat commissions. There reason for this is obvious. Prices to producers are highest when there is a strong export market. Profitability in agriculture, however, has been the exception, not the rule. Therefore, increased productivity by allowing the producers to spread their per-acre cost of production across more bushels to reduce their per-unit cost of production, has been a key to farmers' survival in recent years.

Assuming, however, that a farmer will, within reason, maximize his production at any price level, producing more at lower prices to reduce his per-unit cost of production, and producing more at higher prices to offset the low price years, the prime consideration for the check-off funds has to be that of finding and generating markets for the grain that is produced. This does not mean, however, that production research should be overlooked. To do so, in my opinion, would be equivalent to sticking your head in the sand.

If you are as much a capitalist as I am, then you too do not believe that the world will run out of food any time soon, at least on a continuing basis. If world food shortages are allowed to manifest themselves in the form of higher prices, farmers in this country. and perhaps even more important, farmers elsewhere, will respond with higher production. There, of course, may be a time lag between the shortage and the price reaction and the production response, during which the situation could become uncomfortable, but I am convinced that the response will be there, just as it has been in the past. I am equally convinced that in the future, under our marketing system, after periods of tight supplies and high prices, there will be periods of over production and lower prices, and the cycles will continue just as they have in the past.

Therefore, the continual development of new varieties that are resistant to diseases and can tolerate extremes in weather, would be necessary to optimize opportunities to harvest a crop each year. The development of pesticides, fungicides, agronomic practices and, of course, high yielding varieties, that will minimize costs of production, will also be necessary as costs increase in the future. Whether this on-going research is, in fact, funded in part by the check-off program or totally through state and federal appropriations, remains to be seen.

Although research will continue to be important to the wheat commissions, my personal opinion is that across the board, wheat research financed through check-off collections will gradually trend downward as the demands of the export market development program grow. And these demands for the export market development programs have grown significantly in the last five years and it appears they will continue to grow in the future. Total funding for research should peak periodically as new states establish check-off programs and as existing states increase the levels of their check-offs. But unless the national wheat organizations substantially modify their operations to limit their overhead and program expense, which is doubtful in the near to medium term because of the long-term effects of the embargo, these organizations will continue to demand more and will receive more of the wheat grower money from the member states.

In one state, the legislature mandated the percent of revenue to be allocated to the wheat research program and for many states, particularly like Minnesota and Montana where the word "research" is build into our organization's name, it would not be politically wise to cut out grants for wheat research completely. But the primary emphasis will be placed elsewhere. Therefore, it is important that the University and experiment station personnel work with the various wheat commissions and with their state legislatures to assist in the creation of new check-off states, and to increase check-off levels in the existing states to be sure funds are available to meet both export and domestic needs.

ATTACHMENT #1

1981-82 CHECK-OFF FUNDED WHEAT RESEARCH REPORT

| STATE | CHECK-OFF | TOTAL REVENUE | RESEARCH DOLLARS | % OF TOTAL | NEW VAR. | % | AGRON. PRAC. | % | DISEASE CONTROL | % | QUAL. | % | TRANS. | % | MKTG. | % | OTHER | % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| COL. | ½¢/bu. | 418,000 | 24,000 | 5.7 % | 18,000 | 75 % | ------- | ------ | ------- | ------ | ------- | ------ | 2,000 | 8 % | 4,000 | 17 % | ------- | ------ |
| IDA. | 1¢/bu. | 840,981 | 265,557 | 31.6 % | 116,130 | 44 % | 88,950 | 33 % | 9,200 | 4 % | 38,277 | 14 % | ------- | ------ | 13,000 | 5 % | ------- | ------ |
| KAN. | 3 mills | 817,252 | 80,000 | 9.8% | ------- | ------ | ------- | ------ | 15,000 | 18.7 % | 17,000 | 21.3 % | ------- | ------ | 18,000 | 22.5 % | 30,000 | 37.5 % |
| MIN. | 1¢/bu. | 1,042,086 | 145,500 | 14 % | 19,000 | 13.1 % | 5,500 | 3.8 % | 49,000 | 33.7 % | 36,000 | 24.7 % | ------- | ------ | ------- | ------ | 36,000 | 24.7 % |
| MON. | ½¢/bu. wheat 1¢/bu. barley | 994,525 | 122,244 | 12.29% | 43,000 | 35.18% | 46,995 | 38.94% | 21,400 | 17.51% | 10,849 | 8.87% | ------- | ------ | ------- | ------ | ------- | ------ |
| NEB. | ½¢/bu. | 534,411 | 93,300 | 17.5 % | 21,500 | 23 % | 22,100 | 23.9 % | 18,600 | 20 % | 21,000 | 22.5 % | ------- | ------ | ------- | ------ | 10,100 | 10.8 % |
| ND | 3 mills | 780,000 | 114,000 | 14.6 % | 35,000 | 30.7 % | ------- | ------ | ------- | ------ | 27,000 | 23.7 % | 52,000 | 45.6 % | ------- | ------ | ------- | ------ |
| OKL. | 3/4¢/bu. | 1,230,883 | 451,210 | 36.7 % | 151,760 | 34 % | 217,850 | 48 % | 11,500 | 3 % | 30,100 | 7 % | 15,000 | 3 % | 15,000 | 3 % | 10,000 | 2 % |
| ORE. | 2¢/bu. | 1,250,000 | 252,792 | 20.2 % | 106,000 | 42 % | 64,000 | 25 % | 82,792 | 33 % | ------- | ------ | ------- | ------ | ------- | ------ | ------- | ------ |
| SD | ½¢/bu. | 350,000 | 62,500 | 17.9 % | 11,500 | 18.4 % | 41,400 | 66.2 % | ------- | ------ | 9,600 | 15.4 % | ------- | ------ | ------- | ------ | ------- | ------ |
| TEX. | ½¢/bu. | 200,000 | 20,000 | 10 % | 5,000 | 25 % | ------- | ------ | 5,000 | 25 % | 5,000 | 25 % | 2,500 | 12.5 % | 2,500 | 12.5% | ------- | ------ |
| WASH | .0025% net rec. to grow. | 1,200,000 | 400,000 | 33.3 % | 120,000 | 30 % | 140,000 | 35 % | 100,000 | 25 % | 40,000 | 10 % | ------- | ------ | ------- | ------ | ------- | ------ |
| WYO. | | | -NONE--AL | L THROU | GH U.S. | WHEAT-- | LIMITED | BUDGET | | | | | | | | | | |
| TOTAL | | 9,658,138 | 2031103 | 21.03% | 646,890 | 31.85% | 626,795 | 30.86% | 312,492 | 15.39% | 234,826 | 11.56% | 71,500 | 3.52% | 52,500 | 2.55% | 86,100 | 4.24% |

Does State law dictate how much spent and where spent or which project? All states replied no except Oklahoma. State dictates that 20% be spent on "Wheat Research" to Oklahoma Wheat Research Foundation.

# PRESENT AND PROSPECTIVE INDUSTRY WHEAT RESEARCH

A. Richard Baldwin
Vice President and
Executive Director of Research, Cargill, Inc.,
Minneapolis, Minnesota

Jerry Rees asked me a year ago to cover the future role of private industry research and development in wheat, wheat product markets, and grain-handling technology. It was much easier to accept the assignment last year than it was to prepare my remarks for today.

Before we take a look at the future, let's examine some history of the relationship between public and private wheat research. It is often difficult for anyone to separate the accomplishments of public and private-sector research. I trust that these remarks today will not be construed by my public-sector research friends as trying to give the private-sector credit for any of their very important research. I only want to amplify the importance of agricultural research and call attention to some of the areas where the private-sector also is deeply involved.

Industry research has been inspired by the non-proprietary research conducted by the Agricultural Research Service and at land-grant universities as well as at other public-sector institutions. Companies take this basic research and then develop products or services that meet consumer needs while expanding markets for wheat and wheat products.

Private industry does this for a very sound reason. Companies generally cannot justify spending for non-proprietary research that doesn't pay back investment for 15 or 20 years. In my view, the laudable goals of publicly funded research are: to do research on problems that have little or no proprietary potential; to eliminate duplication of effort, and to make public research relevant to contemporary concerns.

Today, the Agricultural Research Service and State Agricultural Experiment Stations spend about $1 billion annually on agricultural research. That level of research investment is matched by private industry. In wheat research, federal budgeting by ARS and the Cooperative State Research Service is reported to be $18.2 million -- with private companies matching or exceeding that investment. The public and private sectors are committed to, and investing in wheat research together, and each benefits from the other's advances.

A recent advance in the private sector was development of new wheat hybrids either through chemical agent adaptation -- gametocides -- or through more lengthy cytoplasmic breeding. Details of these advances will be covered tomorrow on the program, but hybrids have generally improved yields 10 to 20 percent over recently released, advanced public or private pure-line varieties.

Companies that either have been or are in the forefront of wheat breeding research include, in alphabetical order: Agro-Genetics, with Jim Wilson's Trio Research in Wichita and Seed Research Associates, Kenny and Betty Goertzen's Scott City, Kan., operation; Cargill, which recently introduced genetically-bred hybrids after a 16-year research and development commitment; Coker's, which pre-dates others in private research with soft red winter wheat varieties; DeKalb, which made valuable contributions to the state of hybrid research; Monsanto, which acquired DeKalb's hybrid research operations; and Northrup-King, which emphasizes varietal improvements and has discontinued hybrid wheat work.

Others include: North American Plant Breeders, which is researching pure-line varieties and some gametocides; Pioneer, which currently offers varieties and is developing hybrids; Rohm & Haas, which revolutionized wheat hybrids with its HYBREX chemically induced breeding program; and Western Plant Breeders, which offers pure-line spring wheat varieties.

The International Plant Research Institute also may have a wheat breeding program, but I don't know much about it. It may be aimed at increased salt tolerance or improved protein content.

In addition to those companies, in the last 18 months some 25 patents have been applied for on gametocides. Besides Rohm & Haas, which is a leader in the field, Monsanto is active in this area as the purchaser of the DeKalb program. Also, Union Carbide and Shell Chemical are reported to be pursuing this area. There are others. From this brief summary you can be assured that there is a real private-sector commitment to increasing wheat productivity.

Another important research area is investigation of grain dust explosions in elevators. This has been the focus of extensive postharvest research in both the public and private sectors. Recommendations by the National Academy of Sciences (NAS) said improved housekeeping, reduction of ignition sources, and employee education are the keys to eliminating elevator explosions. However, the NAS report said those proposals were only "a beginning step" in dealing with the explosion problem.

A beginning step in private industry was the founding of the National Grain & Feed Association's (NGFA) Fire & Explosion Research Council. Since late 1978, NGFA has invested nearly $1 million to sponsor 27 practical research projects on the problem. The industry's financial commitment to explosion research will total close to $3 million.

Concurrent with these research projects, industry research, design studies, and marketing developments have changed the way we handle wheat and wheat products. Grain elevators are now being built with elevator legs outside the confined space of concrete elevator structures. In that way explosion damage may be confined to the leg without destroying an entire elevator.

Cargill has researched and developed slow-speed, large-bucket elevator legs that reduce the amount of grain dust in suspension within the elevator leg and at the top of the leg. Polyurethane elevator buckets that reduce ignition sources and improved monitoring systems that detect "hot spots" in the elevator are other equipment innovations. Motion-sensing systems that detect overloading or plugging of equipment, improved slow-down detection devices that detect overheated bearings, conveyor failures or belt friction, and sophisticated dust control systems also have been introduced.

Our company also has done extensive research on the types of dust, moisture levels of dust, dust suppression techniques, and flame propagation studies as part of its investigation of grain dust explosions.

On the marketing scene, Cargill research and transportation studies helped develop unit-train shipments of Midwestern bulk flour to the East Coast. Interstate Commerce Commission approval of 55-car unit trains from Midwestern mills to Eastern bakers has preserved some important flour milling capacity and helped make flour milled in the Midwest price-competitive on the East Coast.

Flour millers remain the primary domestic market for wheat. In 1979-80, millers produced 283 million hundredweights, just two million short of the post-war peak.

This increase in flour consumption -- from a low of 221 million cwt in 1953-54 -- reflects a society with smaller households, second incomes because women are working outside their homes, and an increase in fast-food restaurant trade. The development of a variety of ethnic and high-protein breads also has enhanced flour use. This trend could continue if methods of increasing wheat protein can be developed in the future.

Let's talk now about some possible private-sector wheat innovations of the future. Research must continue on wheat hybrid yields, disease resistance, increased winter hardiness, plus some drought and salt tolerance. More work also must be done to reduce the cost of producing hybrid seeds.

Future wheat-breeding breakthroughs will be achieved with contemporary breeding techniques and genetic engineering. Although genetic engineering will not produce the instant success some laymen anticipate, it should be a top priority for further private-sector wheat research. Much of the world will be increasingly dependent on the United States for food.

Wheat is the major crop that is readily adaptable to colder weather. Genetic engineering may help us develop improved winter hardiness, promote earlier germination vigor and breed in drought and salt tolerance, change protein contents, alter starch compositions, etc. Salt tolerance will become increasingly important in the future as soils or irrigation waters with higher saline contents are relied on to produce more wheat. We eventually should be able to identify segments of chromosomes that transmit any desired characteristics. A major challenge is to be able to alter wheat plants to maximize the use of the solar energy available to them. Now, the best of our crops recover only about 2 percent of the energy they receive from the sun. Theoretically, in photosynthesis plants can use up to 12 percent of the solar energy available. Genetic engineering could be crucial to making such goals a reality.

Other areas to improve are the protein content and amino acid balances in wheat. Protein and lysine work begun by the CIMMYT program in Mexico and at the University of Nebraska by Dr. Virgil Johnson should be further developed in the private sector. It's a long process to increase protein content or change amino acid balance in wheat, but I understand that the Goertzens in Scott City have an active proprietary research program that should be augmented by others.

While increasing wheat's protein content is one way to improve wheat product nutrition, another is protein supplementation. By supplementing wheat flour in commercially baked breads with 5 percent soy flour, the protein level in breads can be increased 12-15 percent. That capability can make the difference between good nutrition and malnutrition to millions of people -- today and in the future. Work done by Bill Hoover and Arlin Ward at Kansas State University and Max Milner at M.I.T. has shown that protein supplementation works. Their work warrants private-sector marketing studies, evaluation of new markets, and promotion of protein-supplemented breads.

Another important key to future wheat productivity will be the ability of researchers to develop more effective methods of controlling diseases, insects and weeds. Significant advances are occurring in weed control research. Companies are now developing herbicides that can be applied at a rate of 7 grams per acre and effectively control weeds within crops that have a 600-gram-per-acre tolerance to the compounds used. This shows important potential for reducing crop protection costs. Public and private-sector researchers are developing together rope-wick applicators, roller-wiper applicators, recirculating sprayers and other techniques that put maximum amounts of herbicide on weeds and only minimal amounts on crops. These could provide significant improvements in herbicide safety and reduce chemical control costs per acre.

Companies that I'm aware of which are leading the way with this brand new generation of selective herbicides that control weeds not previously controlled by current products are American Hoechst, American Cyanamid, BASF, Wyandotte, DuPont, ICI Americas, Monsanto and Shell. I'm sure there are others that have not come to my attention. These new herbicides have broad-spectrum weed control effectiveness and large margins of safety. They also can be applied in mixtures of new and existing herbicides on a crop rotation basis as part of an integrated weed control program.

Among disease-control herbicides, systemic fungicides that have been developed largely in Europe are the latest breakthrough. Systemic fungicides developed by Bayer, Ciba-Geigy and others for seed treatment and field foliage applications have significantly increased disease control capabilities. The systemics appear to be a way of the future, but continuing research on improved efficacy, impact on the ecosystem, and plant characteristics is needed.

Future herbicide research and development success depends on understanding better than we do the fundamental biology of weeds so we can exploit their specific vulnerabilities. We also need to understand how to use these revolutionary new compounds safely and effectively without endangering our soils, plants, animals, and water.

On the insecticide front, synthetic pyrethroids are the big news. Their quick knockdown capability and improved plant safety have established them as a significant new class of insecticides. They are extremely toxic to a broad spectrum of insects while safe to mammals, offer marked improvement in efficacy over standard insecticides and have longevity on foliage but short half-life in soil ecosystems. In addition to their lethal effects on eggs,

larvae, and adult stages of many insects, they also possess repellency properties that cause behavioral changes such as dispersal, loss of appetite, and hyperactivity.

It's estimated that within the next five years, 25 percent of all insecticides used will be synthetic pyrethroids. That's a double-edged sword for researchers. Enthusiastic initial use could lead us down the familiar path of rapid insect resistance. That places responsibility for determining proper timing and the right amounts of synthetic pyrethroids to be used on researchers' shoulders. At the same time, the search for improved synthetic pyrethroids must continue.

In the next 5-10 years there will be a fairly large increase in the use of biologicals such as viruses, bacteria, and antifungal agents as insecticides. The Japanese have been developing *Bacillus thuringensis*-type bacteria for some time. I anticipate some major announcements from them within the next couple of years. In the United States, companies such as mine and Bio-Link and Cytozyme have been working closely with land-grant universities on biologicals that offer growth-promotant benefits.

The real advantage biologicals have over other insecticides or growth promotants is their relative -- I stress relative -- ease of registry with regulatory agencies. There is an increasing number of companies that are showing interest in biologicals, and I expect more research in the future.

I believe further proprietary research also should be done to develop insect suppression techniques such as radiation-induced genetic debilitation, inherited genetic sterility, and pathogen distribution.

This is particularly important now, because we are entering an era of increasing grain storage at a time when insect pests have begun exhibiting resistance to insecticides that attack their nervous systems. That means substitutes must be found for malathion and other common storage compounds in case resistance to them increases. Some of the most promising developments appear to be in substances that arrest insect growth. Maag Agrochemicals in Europe, which is affiliated with Hoffmann-LaRoche, already is active in producing compounds that attack eggs, larvae, and adult insects. More work of this type will be needed if we are to continue winning the battle to preserve our stored grains.

Fertilization techniques also have been improving. Fertilizer banding -- putting combinations of anhydrous ammonia liquids below the seed-planting level of the soil -- before or while

planting has increased yields 10-15 percent. The banding technique has been used for some time in the Palouse Region of Washington and is now spreading to other wheat-producing regions.

Another fertilization practice that's promising is split application of nitrogen. Studies funded by the member companies of the Potash & Phosphate Institute and the Foundation for Agronomic Research have achieved yields of more than 100 bushels per acre in soft red wheat fields by using split applications of nitrogen. In those same studies, scientists are researching the best ways to manage very narrow row spacing of wheat (2-3 inches apart); very high seeding rates (2-3 bushels per acre); high nitrogen amounts; use of fungicides; and use of cycocell. Cycocell is a widely used chemical in Europe that reduces plant height and enables the wheat plant to use large amounts of nitrogen without lodging.

Suspension-seeding techniques also have worked well in the higher humidity climates of Indiana, Ohio, and the Southeastern United States. However, much more work will have to be done on this and the other fertilization methods to reduce their cost and increase their practicality for the majority of wheat fields.

On the equipment front, there appears to be a trend toward minimum tillage practices to conserve soil and water. This trend signals a need for development of new types of planters, plows, chisels, and disks that can provide the agronomic foundation needed to produce a good wheat crop in minimum tillage residue. John Deere Co., Crust Buster, and Tye Manufacturing led the way in developing heavy-duty drill planters for setting seed properly through the surface residue of minimum tillage fields. International Harvester also has adapted its cyclo-planter technology to wheat planting needs under minimum tillage conditions.

Air seeder technology also is improving. Flex King Corp. of Quinter, Kan., has developed a seed planter that also simultaneously knifes fertilizer beneath the seed planting level. Prasco, Wilrich, Friggstad, and John Deere and others also offer air seeding equipment.

From the developments I've highlighted -- and I emphasize they are highlights because time does not permit a comprehensive list -- you can tell that industry is deeply committed to improving the efficiency and productivity of wheat production. We must retain that commitment because the world 30-40 years from now will need double the amount of food it produces today. This is a greater challenge than we've ever faced before. While American

farmers are the most efficient in the world, they won't be able to meet future challenges with 1982 technology. Much of the basic research will have to be done by public-sector researchers, but private-sector contributions will be equally important. All of those research efforts should focus on developing new hybrids, improving agrichemicals and refining marketing techniques to make wheat and wheat products more price competitive. I have full confidence that private and public-sector research will continue to work together to help equip American farmers to meet the wheat production challenges they face in the future.

# PACIFIC NORTHWEST STEEP PROGRAM: SOIL AND WATER MANAGEMENT

R. I. Papendick
Agricultural Research Service
U.S. Department of Agriculture
Washington State University
Pullman, Washington

The Pacific Northwest wheatlands are plagued with an erosion problem that is now recognized as being among the most serious in the nation, and one which each year costs the region millions of tons of top soil that are washed from its croplands. In some places, with conventional farming practices, as much as 12 bushels of top soil are eroded for each bushel of wheat produced. People are becoming more and more aware of the serious consequences of soil erosion wherever it occurs and the serious threat that it creates on future production capability. Our ability to maintain high yields in erosion-prone areas like much of the Northwest will depend more and more in years to come on our ability to check the loss of topsoil.

The cause of the serious erosion in the Northwest is from a combination of factors including (1) a winter precipitation climate with frozen soil runoff, (2) steep, irregular topography, and (3) management and cropping systems that often leave the soil exposed going into the winter rainy season. This is especially true of fall-seeded wheat and barley and of extensive fall moldboard plowing done in preparation for the following spring planting in the higher precipitation areas. In other words, with many conventional practices the soil is "set up" for erosion when winter begins.

Along with erosion, the lack of moisture during the growing season is a problem that confronts most growers and limits wheat production, especially in the dryland areas. In the wheat-fallow areas of eastern Washington, water use efficiency with some of the better management practices amounts to 1 1/2 to 2 1/2 bushels of grain produced for each inch of precipitation received. Scientists in Israel are presently claiming water use efficiency of twice this or more with winter wheat in similar rainfall areas; that is, they are producing the same yields in one year that we obtain in two, which includes a year of fallow. Thus, practices are needed which conserve rain and snowmelt and slow moisture loss by evaporation and weed transpiration along with improved varieties that make more efficient use of the stored water.

For these reasons, soil and water management research is an important component of the STEEP program (Solutions to Economic and Environmental Problems) in the Northwest. To achieve the objectives of erosion control and water conservation, much attention is being given to research on development of conservation tillage for use in small grain and grain-legume cropping systems. By conservation tillage, we mean to include "residue" or "trash" farming where crop residues are managed by keeping

them on the surface as much as possible by using a minimum amount of tillage, or using no-till and planting directly into the residues of the previous crop. With these practices, erosion on most croplands can be reduced to virtually insignificant amounts. Not only does this help solve the erosion problem, but it also helps to conserve water because crop stubble on the surface slows runoff, enhances infiltration, and reduces evaporation.

On the negative side, crop yields with conservation tillage systems are often less than with conventional tillage planting for reasons not always understood or easily explained. The main physical difference between conventional tillage systems and that of reduced tillage and no-till is that with the latter systems the straw which ranges in amount from 2 to 6 T/A is conserved on the soil surface and the seedbed soil is either cloddier or harder. The subsequent crop must take root and grow in the rough untilled seedbed and in the presence of slowly decomposing surface cover. With conventional tillage, the residues are plowed under and with extra cultivations the soil surface at planting time is bare and smooth, but often highly erodible.

Principal areas of research emphasis include studies of crop residue management, cropping systems, fertilizer requirements and application methods, and planting equipment design. The overall objective of the research is to develop new methods or modify existing soil and crop management practices to enhance adoption of conservation tillage systems.

Research over the past 5 years shows rather conclusively that crop residues left on the soil surface benefit overwinter storage of precipitation when precipitation is not sufficient to thoroughly wet the soil profile. For example, in the intermediate precipitation zone, overwinter water storage was increased by 20 percent where the crop stubble was left undisturbed compared with clean fall tillage. Similarly, in a higher precipitation zone, surface residues increased water storage by about one-third on slopes and ridgetop positions of the field where runoff generally occurs.

Unfortunately the additional water saved with surface residues does not always result in higher crop yields. During cool, wet weather, which is often common in the fall, phytotoxins may be produced in the slowly decomposing surface stubble. They in turn may leach into the soil and inhibit seed germination or cause root and shoot injury to wheat seedlings.

Laboratory analysis of wheat straw extracts has shown the presence of short-chain fatty acids which may account for the frequently observed temporary stunting of no-till winter wheat. However, other unidentified toxins of biological origin are likely responsible for the more severe and permanent type injury that often occurs in heavy residues. There is now also preliminary evidence that roots of wheat growing under trashy tillage systems, or where heavy residues are shallowly incorporated, are often more heavily colonized by certain growth-inhibiting bacteria than wheat roots growing in clean tillage systems. Some varieties apparently are

more susceptible to inhibitory effects than others, whereas some, especially older ones, may show high levels of tolerance to effects by these organisms. In laboratory tests, the bacteria which have been tentatively identified as species of pseudomonads have inhibited root growth of some susceptible varieties by up to 50 percent.

Physically removing the crop residues away from the seed row was tested as a means to improve seedling establishment and early growth of wheat where phytotoxicity was a problem. It possibly would also alleviate the abnormal "high crown set" of wheat which often occurs with direct sowing into heavy crop residues. A high crown set impairs development of secondary roots and subjects the young plants to additional environmental stress caused by inadequate water and exposure to herbicides applied for weed control. However, experimental results showed that although stands may be improved, crop yields are not always increased by removing residues from the seed row.

Another crop residue management possibility under experimentation for dryland areas is the concept of strip-till-plant. Wheat is planted in narrow tilled strips (4-inch) with the interrow area left untilled. This once-over planting technique incorporates the crop residues in the seed row, reduces tillage energy requirements compared with conventional planting, conserves seed zone moisture, and provides good erosion control.

A novel approach for crop residue management developed from STEEP research is the slot-mulch concept. This unique development has both the potential for reducing runoff and erosion from frozen soils and enhancing the feasibility of no-till planting in cereal stubble fields. Conceptually, the approach is to compact crop residues into a narrow, continuous slot approximately 3 to 6 inches wide by 10 to 12 inches deep formed preferably on the field slope contour. The residues of straw and chaff are left well exposed above the soil surface. Field trials have demonstrated that during runoff, water will flow into the slot and readily move downward through the residue. The compacted residue insulates the soil and prevents freezing at the base of the slot. The slot depth can be varied within limits to protect against soil freezing for different climatic conditions. Utilizing the excess, loose straw following harvest of a cereal crop for slot mulching should reduce the mechanical seeding, phytotoxic, and microbiological problems associated with no-till planting. Volunteer grain and weed growth should also be reduced because many seeds are collected along with the crop residues and are destroyed by composting in the slot. In a way slot mulching would serve as a method of field sanitization which, in contrast to burning, enhances rather than results in a loss of soil and water conservation benefits.

Studies of crop sequence effects show that highest overall yields of winter wheat with no-till are obtained where the crop follows a low residue crop such as peas or lentils. No-till planting of winter wheat following these grain legumes is now well along to becoming a common practice with growers in eastern Washington and adjacent Idaho, and wheat yields equal or sometimes exceed those obtained with conventional tillage planting. Yields

are often much lower where wheat is no-till planted following a cereal crop unless the previous crop was sparse, or the residues were removed by harvesting or burning. At this time there is very little direct drilling of small grain crops into cereal stubble. The STEEP effort is further attempting to identify potential alternative crops such as oilseeds and to test for their adaptation to Northwest climatic conditions and cropping sequences in no-till systems.

No-till management offers distinct possibilities for more intensive cropping in the low to intermediate precipitation areas (12- to 15-inch average annual precipitation) where alternate wheat-fallow previously has been the more traditional practice. The scheme under investigation is designed to control weeds chemically and allow the stubble of the previous crop to stand overwinter. This method would increase water storage most years compared with fall cultivation which would reduce surface cover. Instead of the usual fallow cultivation, a spring crop such as barley or spring wheat is no-till planted as early as conditions permit in the spring. Without the conventional tillage for seedbed preparation, water loss by evaporation is minimized because the soil is not disturbed. The potential for crop yield is increased with the extra water saved both by the stubble overwinter and the no-till planting. In addition to a greater overall production, the substitution of cropping for fallow provides more continuous soil cover and, hence, more erosion control as well as greater water-use efficiency.

A significant technology advance for no-till planting as a result of STEEP research is direct seeding of cereal crops in killed grass sod. A considerable acreage of bluegrass for seed production (approximately 80 percent of the nation's seed supply) is grown in northern areas of the Palouse region on sloping, highly erodible soils. When in sod, the soils are well protected and there is virtually no erosion. Following sod take-out by the usual practice of plowing and cultivation for seedbed preparation, the erosion hazard is again increased. It was found that a registered herbicide, glyphosate (N-(phosphonomethyl)glycine), could be applied at an economical rate to kill the bluegrass crop in early spring after which a cereal crop, wheat or barley, could be no-till planted and grown to produce yields equivalent to conventionally planted crops. This first crop can then be followed by winter wheat, a grain legume, or another spring crop and a rotation established with no-till planting continued on the undisturbed sod. In this way, the protection against erosion by the intact sod, which deteriorates very slowly, remains highly effective for several years after which the field may be returned to the grass phase of the rotation.

Killing seed-bluegrass stands in the fall with glyphosate and no-till planting winter wheat in sod does not appear to be a viable approach because bluegrass then is water stressed and difficult to kill, and the decomposing bluegrass thatch is often phytotoxic to the winter wheat. Also, winter wheat tends to winter kill in undisturbed bluegrass sod.

No-till systems are found to generally require more nitrogen, phosphorus, and sulfur fertilizer for maximum wheat yields than conventional planting systems. For example, in one long-term rotation experiment, 105 lbs of nitrogen per acre were required for maximum yields of winter wheat with conventional tillage compared with 140 lbs per acre for no-till. The study also showed lower soil nitrate levels with no-till compared with tilled seedbeds. In other experiments, placement of nitrogen fertilizer as a band below the seed row was found to be advantageous for no-till planted spring crops but not for winter wheat. Another benefit of banding fertilizer was less weed growth between the crop rows and hence, less competition to the crop. There appeared to be no differences in crop response among the various sources of nitrogen.

Cropping systems and cultural practices for wind and water erosion control on sandy irrigated soils is also a part of the STEEP soil management research. Soil erosion from furrow irrigation was found to be greatly reduced with small amounts (0.2 T/A) of crop residues present in the furrow. However, yields of some crops such as corn can be reduced with the addition of residues in the furrow even with the small amounts used to control erosion. Wind erosion is often severe on sandy soils during establishment of crops such as potatoes because of lack of protective ground cover at the time the crop is emerging. A reduced tillage-potato planting system was developed which utilized strip tillage 15 to 18 inches in width for incorporation of insecticides, herbicides, and fertilizer. The crop residues left between the rows provided excellent protection against wind erosion during crop establishment. Related studies showed that winter wheat is one of the best cover crops for wind erosion control in the sandy soil irrigated areas. Spring cereal crops winter kill and surface cover is not retained when needed. Other plant species such as winter rape, ryegrass, and hairy vetch do not produce enough growth in the fall for adequate ground cover.

Planting equipment design has received considerable emphasis in the STEEP program. Several versions of no-till or reduced tillage planters for one-pass operations were developed and tested, each with varying degrees of success. One, a chisel-type planter, resulted in yields of winter wheat on commercial fields that were 107 percent of conventionally seeded fields, and soil erosion was reduced by 84 percent as compared with conventional plantings. Another with a hoe-type opener was designed to operate in heavy residues and to provide for precise vertical separation of seed and fertilizer below the seed and thus minimize damage to seedling roots from fertilizer burn. Another type of drill constructed with heavy disk-type openers was also capable of operating in heavy residues and hard soil. Several commercial no-till drills with this design are currently in use in the Palouse region. It appears that several different drill designs will be necessary for no-till planting because of the diverse soil, slope, crop residue, and moisture conditions that occur across the wheat region.

# IMPACT OF WHEAT BREEDING AND GENETICS ON THE PACIFIC NORTHWEST STEEP PROGRAM

R. E. Allan
Agricultural Research Service, U. S. Department of Agriculture, and Washington State University, Pullman, Washington

Adapting wheat to erosion-reducing management systems is a formidable challenge to wheat breeders, especially in the U. S. Pacific Northwest where severe erosion chronically occurs on fall-sown winter wheat. Major breeding emphasis has been directed toward two approaches. The first approach has been to breed wheat genotypes adapted to early fall seeding on summer fallow. The second approach emphasizes development of wheat strains and populations adapted to conservation or reduced tillage for annual crop rotations.

Early seeding has long been recognized as a practical way to reduce erosion. In fact, a primary objective of O. A. Vogel's pioneering work on semidwarf wheats was to develop strains that could efficiently use high levels of fertilizer, withstand lodging, and be sown early to afford maximum vegetative cover for erosion control. The problems associated with early seeding are fairly well defined and definite progress has been made toward overcoming them. The main problems associated with early seeding relate to weeds, diseases, insects, and weather-related plant stress. Breeding has already reduced the vulnerability of early sown wheat to cold stress, lodging losses, poor stand establishment and several diseases.

Developing wheats for conservation tillage is more complex and breeding has made little impact since STEEP began. Progress has been slow because most limiting factors of conservation tillage are either unknown or poorly understood. Furthermore, traits desired of wheats adapted to early seeding may differ from those needed for conservation tillage.

Although a good start has been made, we still know very little concerning the complex interactions that affect wheat plants when grown under conservation tillage. The potential complexities of these interactions seem awesome when we ponder the numerous permutations possible among such interacting forces as weeds, insects, pathogens, rodents, and residues upon wheat plants. These biological forces become more complicated because they also interact with physical forces of soil, its nutrients, water, temperature, and light. Elucidation of these complex problems calls for long-term multidisciplined research. Work of this scope has only been underway a few years and information that has directly aided breeders has been meager. Pathologists have succeeded in identifying some of the diseases that are most important under conservation tillage including a vascular disease called fungus stripe, caused by *Cephalosporium gramineum* and root rot caused by *Pythium* sp. that becomes particularly aggressive with conservation tillage. Microbiologists have evidence that certain bacteria that abound under conservation tillage markedly inhibit the growth of wheat seedlings. These

microbes inhibit growth of some wheat strains less than others, suggesting that tolerance to them may be developed. Entomologists have learned that the hessian fly, a pest that remained quiescent for several decades in the Pacific Northwest, can become destructive under conservation tillage. Knowing how to best subjectively evaluate plants grown under conservation tillage for stress symptoms has been puzzling. Researchers at Pendleton, Oreg., have developed a "tiller-leaf reading system" that has promise for telling when a wheat plant received stress. This could prove to be a useful selective device for breeders. Other key discoveries have been made concerning soil nutrients, weeds, pesticide use, and residue management under conservation tillage which may prove to have direct bearing in breeding wheats for conservation tillage.

To properly assess the impact that breeding can make toward erosion control, we need to examine the problems of the early seeding and conservation tillage erosion control strategies. Diseases are foremost among the limitations to both systems. Table 1 lists 17 wheat diseases that occur in the Pacific Northwest. I have indicated whether the disease is a limitation to early seeding or conservation tillage. Stripe rust, leaf rust, flag smut, strawbreaker foot rot, dryland root rot and barley yellow dwarf virus are high risk diseases under early seeding. Leaf rust, common bunt, take-all, fungus stripe and possibly stem rust, dwarf bunt (TCK) and plant growth-inhibiting bacteria rate as high risks under conservation tillage. Most diseases have divergent ratings under the two systems and require separate research programs.

I have assigned a rating for the potential impact of breeding toward control of these diseases. Except for take-all, Pythium root rot, and growth inhibiting bacteria, I believe breeding could have intermediate (5-7) to high (8-9) impact. Currently achieved breeding impact is rather low or nil for all diseases except stripe rust, powdery mildew, flag smut, and common bunt.

Table 2 indicates major insects and rodents affecting early seeding and conservation tillage in the Pacific Northwest. As with diseases, the two management systems appear threatened by different pest problems. The potential and achieved impact of breeding is much lower than for diseases. Except for hessian fly, breeding as a means of alleviating these problems may have small or passive impact.

Weather and management-induced plant stresses affect both erosion control strategies (Table 3). Spring frost tolerance, seedling vigor, lodging resistance, weed competitivity, herbicide tolerance, and synchronized plant growth rank high for both systems. Coldhardiness and water stress also rate high for early seeding, whereas plant heaving, sprout damage and perhaps nutrient imbalance and toxic residues are high for conservation tillage systems. Several of these factors are designated with a "?" because conclusive evidence as to their importance has not been secured. There appears to be intermediate to high potential for breeding of all traits except nutrient imbalance and residue phytotoxicity. Achieved breeding progress indicates that considerable improvement can be made.

Weeds are major limitations to both strategies. Work at Washington State Univ. and elsewhere has demonstrated differential tolerance of wheat germplasm to metribuzin and several other promising herbicides. Limited evidence also suggests that wheat strains may differ in their competitiveness with weeds. Wheat strains that resume growth slowly in the spring or that fail to canopy above grassy weeds are particularly disadvantaged.

Table 4 gives combined ratings of several wheat varieties for the main constraints to early seeding. Definite progress has been made by breeders when their most recent releases are compared to 'Nugaines'. More effort is needed to combine these desired traits. A rating of 52 could be achieved by combining the highest ratings of these seven varieties.

During the past 6 years my colleagues and I have concentrated on testing genetically diverse wheat strains and populations under tilled and reduced tillage systems. We used split plot designs in these tests where the different wheat strains were the main plots and the various tillage treatments were the sub-plots. We have conducted over 50 of these tests on various residues. Our objectives were to identify wheat strains best adapted to reduced tillage by comparing their performance under the two cultures. We have not yet found a universal wheat prototype for conservation tillage culture. Differences between tillage and reduced tillage were significant in 55% of my tests conducted over a 4-year period. Interactions between wheat strains by practice and wheat populations by practice were significant in 15% and 35% of the comparisons, respectively. Fourteen traits were affected by tillage practice, including agronomic, disease, and quality criteria (Table 5). Tests of this type are most notable for their inconsistencies. Tillage practice caused both negative and positive effects for 8 of the 14 traits. We have found the trait affected may vary among populations and that genotype by tillage practice interactions varied among tests and years. These inconsistencies have masked meaningful interpretations regarding performance of individual wheat strains or populations. The tests have identified some plant traits to consider in selecting germplasm with specific adaptation to conservation tillage. They include: improved stand establishment, rapid early plant growth, early maturity, weed competitiveness and resistance to diseases favored by conservation tillage.

Inconsistencies among the performances of wheat genotypes under conservation tillage over different seasons and locations has been the rule. Limitations such as poor stands, low tillering, delayed plant growth in the spring, and late heading may be serious one season or at one site but not for others. To counter such unpredictable limitations, wheats developed for conservation tillage need to have special fitness and yield plasticity. For example, if stand or tillering are reduced, compensation is needed in increased kernel weight, or kernels per spike, or both.

After six seasons and 56 site/years of tests involving over 500 different wheat strains, we have learned that generally adapted wheats have the best overall performance under conservation tillage. Generally or widely adapted types can buffer against the unexpected event. Many of the fitness and stability properties attributed to varietial mixtures and multilines make

them viable choices for use in conservation tillage systems. We are now placing special emphasis on evaluating such genetically heterogeneous material.

Because screening genetically fixed germplasm under conservation tillage management was unrewarding, we now grow early generation, genetically plastic populations in conservation tillage tests. From the first segregating generation on, these wheat plants and populations know no other life but conservation tillage culture. We hope that conservation tillage management over time will select out the most fit progenies. This approach has just begun but already genetic shifts in certain traits are apparent.

In conclusion, the development of wheats for conservation tillage systems will require long-term multidisciplined team research. Breeding gains should accelerate once we better understand the complex interactions affecting conservation tillage-grown wheat plants. Over the long term chances of success appear good in breeding wheats for conservation tillage. Fortunately, wheat is the most versatile and widely adapted of all cereals. It has extensive gene pools which include weeds, wild and cultivated forms. To breed the ultimate no-till wheat, we may need to borrow heavily on adaptive properties of wheat's weedy and wild ancestors.

Table 1. Major Diseases that Limit Early Seeding and Conservation Tillage and Ratings for Potential and Achieved Impact of Breeding.

| Disease | Importance† | | Breeding Impact‡ | |
|---|---|---|---|---|
| | Early Seeding | Conservation Tillage | Potential | Achieved |
| Stripe rust | High | Medium | 9 | 7 |
| Leaf rust | High | High | 9 | 3 |
| Stem rust | Low | High? | 9 | 1 |
| *Septoria* species | Medium | Low | 7 | 2 |
| Powdery mildew | Medium | Medium | 9 | 5 |
| Flag smut | High | Low | 8 | 6 |
| Common bunt | Low | High | 9 | 7 |
| Dwarf bunt | Low | High? | 6 | 4 |
| Strawbreaker foot rot | High | Low | 7 | 3 |
| Dryland root and foot rot | High | Low | 5 | 3 |
| Take-all | Low | High | 2 | 1 |
| Cephalosporium stripe | Medium | High | 6 | 4 |
| Snowmolds | Medium | Medium? | 7 | 4 |
| *Pythium* species | Low | High | ? | ? |
| Barley yellow dwarf | High | Low | 5 | 2 |
| Wheat streak mosaic | Medium | Low | 5 | 2 |
| Inhibiting bacteria | Low | High? | ? | ? |

† A "?" indicates that importance and breeding impact of the disease is presently uncertain.
‡ 1 = low, 9 = high potential or achieved impact of breeding.

Table 2. Major Insects and Rodents that Limit Early Seeding and Conservation Tillage and Ratings for Potential and Achieved Impact of Breeding.

| Pest | Importance† | | Breeding Impact† | |
|---|---|---|---|---|
| | Early Seeding | Conservation Tillage | Potential | Achieved |
| Hessian fly | Medium | High | 9 | 3 |
| Green bug | High | Low | 4 | 1 |
| Bird-cherry oat aphid | High | Low | 4 | 1 |
| Other aphids | High | Low | 4 | 1 |
| Wheat curl mite | High | Low | 5 | 1 |
| Wireworms | High | ? | ? | ? |
| Rodents | Low | High | ? | ? |

† A "?" indicates that importance and breeding impact of the pest is presently uncertain.
‡ 1 = low, 9 = high potential or achieved impact of breeding.

Table 3. Stresses that Limit Early Seeding and Conservation Tillage and Ratings for Potential and Achieved Impact of Breeding.

| Trait | Importance † | | Breeding Impact † | |
|---|---|---|---|---|
| | Early Seeding | Conservation Tillage | Potential | Achieved |
| Stress due to weather | | | | |
| Coldhardiness | High | Medium? | 7 ‡ | 4 |
| Frost tolerance | High | High | 5 | 3 |
| Heaving | Medium | High | 8 | 4 |
| Water stress | High | Low | 6 | 4 |
| Desiccation | Medium | Low | 5 | 3 |
| Sprout damage | Low | High | 6 | 3 |
| Stress due to management | | | | |
| Seedling vigor | High | High | 8 | 4 |
| Lodging | High | High | 9 | 7 |
| Nutrient imbalance | Medium | High? | ? | ? |
| Weed competition | High | High | 4 | ? |
| Herbicide tolerance | High | High | 5 | 1 |
| Synchronized growth | High | High | 8 | 4 |
| Toxic residue | Medium | High? | ? | ? |

† A "?" indicates that importance and breeding impact of the trait is presently uncertain.
‡ 1 = low, 9 = high potential or achieved impact of breeding.

Table 4. Ratings of Soft White Wheat Varieties for Several Important Traits Needed for Early Seeding.

| | Varieties | | | | | | |
|---|---|---|---|---|---|---|---|
| Trait | Nugaines | Daws | Stephens | Hill 81 | Lewjain | Tyee | Crew |
| Yield | 6† | 7 | 8 | 7 | 7 | 7 | 7 |
| Coldhardiness | 5 | 8 | 3 | 6 | 4 | 6 | 4 |
| Seedling vigor | 4 | 3 | 7 | 6 | 5 | 4 | 5 |
| Rusts | 5 | 6 | 7 | 5 | 6 | 6 | 8 |
| Strawbreaker foot rot | 3 | 3 | 5 | 4 | 4 | 4 | 4 |
| Cephalosporium stripe | 6 | 4 | 1 | 5 | 6 | 4 | 4 |
| Barley yellow dwarf | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Quality | 6 | 7 | 8 | 7 | 8 | 7 | 8 |
| Total | 37 | 40 | 41 | 42 | 42 | 40 | 42 |

† Where 1 and 9 are the lowest and highest ratings, respectively.

Table 5. The Effect of Conservation Tillage Culture on 14 Traits Studied in Several Tests during 1978 to 1981.

| Trait | Effect of Conservation Tillage Increase | Decrease |
|---|---|---|
| Grain yield | yes | yes |
| Tiller number/$ft^2$ | no | yes |
| Bushel weight | yes | yes |
| Kernel weight | no | yes |
| Plant height | yes | yes |
| Heading date | yes | no |
| Lodging (%) | yes | no |
| Stand (%) | no | yes |
| Post-harvest dormancy | yes | yes |
| Disease severity | yes | yes |
| Falling number value | yes | yes |
| Milling score | yes | yes |
| Protein content | yes | yes |
| Alkaline water retention value | no | yes |

# CHEMICAL FALLOW WEED CONTROL

Donn C. Thill
University of Idaho, Moscow

Fallow is cropland left idle for one growing season while the soil is cultivated to control weeds, conserve moisture, and allow for the accumulation of nitrate-nitrogen. In areas with less than 16 to 18 inches annual precipitation, winter wheat is often grown in a wheat-fallow-wheat sequence. Annually, about 3 million acres are fallowed in the Pacific Northwest, with about 450,000 acres of this occurring in Idaho.

The primary weeds occurring on fallow ground include downy brome (cheatgrass), volunteer winter wheat, cereal rye, jointed goatgrass, mustards, prickly lettuce (China lettuce), pigweed, lambsquarter, kochia, prostrate knotweed, horseweed, and Russian thistle. Fallow management systems presently used in Idaho are black fallow, stubble mulch (trashy) fallow, and chemical fallow.

## Black Fallow

In black fallow systems, a moldboard plow is used to bury all surface straw and chaff, leaving the soil surface bare throughout the fallow period. Generally, a minimum of four tillage operations are used after plowing to control weeds and firm the soil surface for planting. The plow operation can control downy brome, volunteer wheat, and broadleaf weeds during wet falls and spring but leaves the soil surface bare and subject to severe wind and water erosion.

## Stubble Mulch (trashy) Fallow

Stubble mulching leaves crop residues on the soil surface throughout the fallow period to protect the surface from wind and water erosion. If weeds such as Russian thistle are present in the stubble after harvest, cultivation with a sweep plow is necessary for weed control. If few weeds are present in the fall, the field is usually not tilled until the following spring.

The first spring tillage operation is usually done with a sweep plow or one-way disk plow set to till about 6 inches deep. The second cultivation is done with a sweep, chisel plow, disk, or field cultivator and is

shallower than the first tillage. A rod weeder is generally used for all subsequent cultivations.

During wet weather, equipment used in a stubble mulch fallow system may merely transplant shallow, fibrous-rooted grass weeds such as downy brome and volunteer winter wheat. Under these conditions, multiple tillage operations are required. Control is usually not achieved until dry weather prevails. Multiple tillage operations bury excessive amounts of residue, pulverize the soil and leave it susceptible to erosion. Lack of control, however, allows weeds to produce seed and use valuable stored moisture.

In many fallow areas, initial tillage is done in the early spring to control weeds. Once the soil is tilled, very little additional water is stored in the soil profile because of the disruption of the continuous water-conducting pores in the soil. The first tillage operation can also cause the rapid evaporation of moisture and prevent the further accumulation of moisture unless spring rains completely wet the entire tilled zone.

Spring rains can add an additional 1 to 2 inches of moisture to the soil if the early tillage is not performed. A good rule of thumb for the wheat-fallow production areas of the Pacific Northwest is that for each inch of additional water stored in the soil, growers can produce about 6 bushels per acre more wheat. If tillage can be delayed until late spring, the maximum amount of soil moisture stored can be increased. A late spring tillage forms the dust mulch needed to reduce the soil's evaporative loss of moisture. If the initial tillage is delayed until late spring, weeds must be controlled with herbicides to prevent their use of soil moisture and to prevent seed formation.

Chemical Fallow

Fallow management systems using herbicides for weed control in late fall or early spring combined with a delayed stubble mulching tillage are often referred to as chemical fallow. In a chemical fallow system, herbicides are usually applied before any tillage operations are performed. When large Russian thistle plants are present after harvest, however, it is necessary to undercut the stubble with a sweep plow.

Fallow herbicides can be applied in the fall after harvest until freezing temperatures prevent spray application and/or in the spring and summer of the fallow season depending on the type and rate of herbicide used. Table 1 lists the fallow herbicides currently registered for use in Idaho and pertinent remarks pertaining to the use of each herbicide. Always refer to the product's label before using any pesticide.

Proper herbicide application allows growers to delay the initial tillage operation and reduces the total number of tillage operations performed during the fallow period. The amount of time that the tillage can be delayed depends on the degree of weed control the herbicide application gives. Factors such as the herbicide used and rate of application, weather

conditions after application, weeds present, and soil type may influence the effectiveness of the chemical weed control. Contact your University of Idaho Extension county agent for more detailed information about these factors in your production area.

Once tillage operations begin, a conservation tillage program such as stubble mulching should be used throughout the remainder of the fallow period. Planting into a chemical fallow system can be accomplished with conventional planting equipment.

Table 1. Herbicides labeled for fallow weed control in Idaho. Always read the label before using any pesticide.

| Product[1/] | Remarks[2/] |
|---|---|
| Weed problem: Annual grass weeds and some broadleaves | |
| atrazine + cyanazine (Bladex) | Use lower rates on sand to sandy loam soils having an average annual precipitation of less than 10 inches. Use intermediate rates on finer textured soils with 10 to 15 inches annual precipitation and higher rates when the average annual precipitation is greater than 15 inches. Do not spray after Nov. 15 of the year preceding the planting of winter wheat. Only corn or sorghum can be planted the spring after application. Do not apply to calcareous or caliche soil outcroppings. On fallow land having an existing and established weed population, paraquat (Ortho Paraquat CL) may be tank-mixed with atrazine + cyanazine. Use the higher rate when weed growth is particularly heavy or dry weather conditions prevail. Add X-77 nonionic surfactant at the rate of 1 qt per 100 gal of diluted spray when using paraquat. The tank mixture can be applied by ground or by air. |
| dalapon + cyanazine (Dowpon M + Bladex) | Apply to stubble after fall rain but before April 1. Follow only with winter wheat. Refer to cyanazine label for rate and use precautions. |
| glyphosate [3 lb(a.e.)/gal] (Roundup) | Apply to actively growing weeds that are less than 6 inches tall. |
| glyphosate + 2,4-D amine (Roundup + 2,4-D amine) | Will control some additional broadleaf weeds such as kochia, lambsquarter, prickly lettuce, Russian thistle, and redroot pigweed. |

| | |
|---|---|
| glyphosate + dicamba (Roundup + Banvel) | Will control some additional broadleaf weeds (see weeds listed under glyphosate + 2,4-D amine remarks) and provide short-term residual control of selected broadleaf weeds (see Banvel label). Use low rates only when weeds are small, less than 4 inches and actively growing. If weeds are drought stressed or 4 to 6 inches tall, use the high rate of glyphosate plus the recommended rate of dicamba. Crop injury may occur if the interval between application and planting is less than 45 days/pt of dicamba used/acre excluding days when the ground is frozen. |
| metribuzin (Lexone) | Use lower rates on coarse soils and higher rates on fine textured soils. Best results are obtained if the application is made before weed emergence or during early stages of weed growth (less than 2 inches tall or across). Do not replant winter wheat within 8 months of treatment. A contact herbicide (used according to its label) may be useful to control volunteer wheat and weeds that are more than 2 inches tall. Treat only where straw and chaff have been evenly spread over the field. Rainfall is necessary for activation of the herbicide (0.5 to 1 inch). |
| metribuzin (Sencor: after harvest application) | Use higher rate for longer weed control or for weeds designated on the label as requiring the higher rate for control. Rainfall is necessary for herbicide activation (0.5 inches or more). Where weed growth is present at application time, Sencor may be mixed with paraquat or other contact herbicides. Refer to the other registered product's label for additional directions, rates, and weeds controlled. Do not plant crops in treated areas earlier than 10 months after fall applications. |
| metribuzin (Sencor: spring applications) | Apply to wheat stubble in spring. Use higher rate for longer weed control or weeds designated on the label as requiring higher rates for control. Rainfall is necessary for herbicide activation (0.5 inches or more). Refer to after harvest application for information on tank mixtures. Wheat can be planted 120 days after the spring application. |
| propham with PCMC (ChemHoe 135) | Do not plant crops in treated area within 8 months of application. Apply after soil |

| | |
|---|---|
| | temperature has cooled to 50°F or cooler at 1-inch depth. Use lower rates on coarse textured soils when plants have 3 leaves or less. Use higher rate on medium to fine textured soils or larger plants. Will not control broadleaf weeds. |

Weed problem: Annual and perennial broadleaves

| | |
|---|---|
| SULV 2,4-D, amine | For fallow land used in rotation to grow wheat, barley, rye, or oats. Do not make application within 30 days of planting. Refer to label for recommended carrier rates. |
| dicamba (Banvel) | For best results make application when weeds are less than 6 inches tall and actively growing. Wheat may be planted in the fall or spring after applications. Crop injury may occur if the interval between application and planting is less than 45 days per pint of product used per acre, excluding days when ground is frozen. |

---

[1/]Trade names are used to simplify the information presented. Use of these names neither implies endorsement of products nor criticism of similar products not mentioned.

[2/]Refer to product label for recommended herbicide application rates.

Benefits of a well-managed chemical fallow system over a mechanical fallow system are:

1. Improved weed control.
2. Increased moisture storage.
3. Fewer tillage operations; saving time, fuel, and money.
4. Reduced soil erosion through an increased amount of plant residue left on the soil surface.
5. Improved crop yield through better weed control, more moisture storage, and better soil conservation.

Some precautions to consider with a chemical fallow system are:

1. Adoption of any new technology requires added knowledge and information.
2. Use of short residual herbicides in a chemical fallow may place restrictions on timing of certain operations such as planting.
3. Once a herbicide is applied, changing choice of crop may not be possible.
4. Available chemical fallow herbicides do not provide good control of perennial weeds. Such weeds must be controlled separately with other herbicides or tillage.

## Chemical Recommendations

The chemical recommendations given here are based on the best information currently available for each chemical listed. If followed carefully, residues should not exceed the tolerance established for any particular chemical. To avoid excessive residues, follow labelled dosage levels, number of applications, and minimum time interval between application and reentry or harvest.

# CONSERVATION TILLAGE EQUIPMENT

R. R. Johnson
Deere & Company Technical Center
Moline, Illinois

Conservation tillage systems are designed to provide a rough, residue-covered soil surface that is resistant to wind and water erosion. On all U.S. crops, conservation tillage is currently practiced on about 30 percent of the planted acreage--about triple the acreage so planted ten years ago. We project that within the next ten years conservation tillage will be used on over half of the planted acreage, making it the predominant system in the United States. No-till represents the extreme form of conservation tillage because seed is planted in a previously undisturbed soil. About three percent of the U.S. planted acreage is seeded with the no-till method, and small grains have accounted for only 10 to 15 percent of this no-till acreage in recent years.

There is no one ideal tillage system. Optimum tillage practices are site-specific, much like fertilizer and crop variety recommendations. Soil type, climate, and crop rotation are factors that influence tillage system selection and often oblige farmers to use different tillage systems on a given farm. The current mix of tillage tools offered by the farm equipment industry makes it possible to produce economically almost any desired type of seedbed. Future research in tillage machines will offer machines with even greater efficiency.

Seeding devices currently available for heavy residue conditions include coulter and hoe drill configurations and the relatively new central metering air seeders that attach to chisel plow or field cultivator frames. The central metering air seeders perform best in the spring wheat areas and have the additional capability of deep-banding fertilizer.

The current selection of wheat seeders, compared with conservation tillage row crop planters, have less planting accuracy and flexibility. This is largely due to the requirement that wheat seeding devices perform under drier soil conditions, less uniform residue conditions, and narrower row spacings than are encountered by row crop planters. Wheat seeders that overcome these problems can be built but are expensive. However, now that air seeders are available with chisel plow frames, it is possible to develop improved ground-engaging tools to overcome many limitations associated with conservation tillage wheat seeding.

# DOUBLE CROPPING

Howard F. Harrison
Coker's Pedigreed Seed Company
Hartsville, South Carolina

Double cropping, by my understanding of the term, may be defined simply as a farming practice by which two crops are harvested from the same land in one year. But the simplicity of double cropping ends with the definition.

Perhaps the best known system involves fall-sown grains followed by soybeans. However, there are numerous examples of other practices where corn, cotton, grain sorghum, beans, vegetables, and other crops are involved.

## Management

Profitable double cropping requires very precise management, not only as it pertains to crop culture, but also with regard to economics. It is possible to be moderately successful in growing the two crops, but still have less net profit than would have been possible with one crop alone. Every day of the frost-free period may be considered as an expendable asset which when spent is not recoverable. The efficient use of this asset is one of the keys to successful double cropping.

Several schemes have been devised to better utilize the frost-free period.

## Drying Grain

Studies at Illinois have shown that by harvesting wheat at 18 to 20 percent moisture, then drying, about six days can be gained, and net profit of the two crops is increased by $12.30 per acre. Another obvious advantage of this system is that weeds are easier to control because they have less time to develop between crops.

## No-Till or Minimum Till

Another concept that has gained rather wide acceptance is either "no-till" or "minimum till" by which the summer crop is planted directly in the wheat stubble. No-till has among its advantages a saving of time required for land preparation, a saving of fuel and machinery wear, and the very important conservation of soil moisture. Erosion control may also be another factor in favor of no-till or stubble planting.

On the other hand no-till presents a problem where heavy residues of wheat plants are left on the soil surface. In some areas, this problem is overcome by simply burning of the fields after combining. In other areas burning is prohibited by law. Burning destroys valuable organic material and tends to dry out the soil surface in addition to being hazardous to surrounding property. Wheat straw is baled and sold at a profit in some instances, but markets are not always available.

A number of companies are marketing special machinery and tools especially for mulch planting; these tools usually involve a system of discs or coulters with enough downward pressure to cut through the litter which allows the new crop to be planted at a desired depth.

No-till also presents special problems with weed control. The use of herbicides must be a part of the system. A working knowledge of the kinds of weeds and proper application of herbicides is absolutely essential.

## Relay Intercropping

Relay intercropping offers still another opportunity to save time. In this system the second crop is interseeded in the standing crop before harvest. In the case of the classic wheat-soybean system, the wheat is planted in greater than normal drill widths, allowing encugh space for the tractor wheels and planting feet. The wheat can then be harvested at the normal time with a well-established stand of soybeans already on the way. Other than problems of management, the main disadvantage is a reduction in wheat yields, probably owing to less stand density.

Experiments with this type of planting at N.C. State University have shown a reduction in wheat and barley yields of from 25% to 50%. Similar reductions are reported from Georgia and Illinois. However, there have been reports of successful application of this practice by certain farmers in Indiana by preliminary research results from Illinois.

## Soil Moisture

A high percentage of the failures in double cropping can be attributed to lack of sufficient soil moisture, especially at planting time. Those growers who can irrigate at critical times are much more likely to succeed year in and year out than those who depend upon rainfall alone. Irrigation, in addition to ensuring fast plant emergence, simplifies the application of fertilizers and herbicides in many instances.

## Varieties

Because I have spent several years attempting to develop improved varieties of wheat, I would be somewhat lax if I failed to extol the virtues of my trade by not mentioning the importance of variety selection both before and after double cropping. The following varietal characteristics of wheat that might enhance double cropping are worth noting here:

Because of time conservation, earliness of maturity would probably top the list. Most wheat breeders would probably agree that one of the more difficult jobs we face is that of breeding varieties that are significantly early but still maintain high yield. The reason for lower grain yields with early maturity is not clear to me, but it could be simply that with a "factory with shorter hours" you get less production. At any rate, any loss of yield from planting early varieties must be weighed against the saving of time.

Plant height may also be a factor. It would seem that short stature is to be preferred over the tall, because of less litter with which to contend in preparing for the next crop. By using all of the dwarfing genes available, it is possible to breed varieties that are probably too short for practical use. Ex-

tremely short varieties may be lower yielding, may not provide a canopy adequate to suppress weed growth, and are thought to be more prone to damage from diseases that are spread by splashing water. An example of such diseases is glume blotch caused by Septoria nodorum.

Lodging resistance or straw strength may also be an important consideration especially where relay intercropping is used.

There seems to be considerable research activity in double cropping and its ramifications. There is interest in the study of allelopathy or the toxic effect of crop residues on the growth and development of subsequent crops. There is some evidence that there may be varietal differences in allelopathy where wheat is concerned. A better understanding of the influence of herbicide residues in multiple cropping systems is also needed.

This brief review of double cropping suggests that the system is a viable option where sound management and adequate resources are available. In addition to the considerations listed, double cropping in some instances improves the cash flow during the early summer when expendidures must be made for summer crops.

# PLANT GERMPLASM RESOURCES

Quentin Jones
Agricultural Research Service
U.S. Department of Agriculture
Beltsville, Maryland

This country, which stands unchallenged as the greatest producer of food that the world has ever known, which exports the production from one acre in three, is dependent upon the rest of the world for its genetic resources (germplasm) of practically all of its domesticated plants and animals because most are not native to the United States. That is why the plant introduction activities started with the earliest European colonists, were formalized by Federal government action as early as 1819, and became the initial core of the U.S. Department of Agriculture when the latter was founded in 1862.

Following the creation of the Department of Agriculture, plant exploration activities increased. Collectors were sent to Europe and China in 1864, the latter for Chinese sorghums. Efforts up to 1898 brought introductions of the navel orange, flax, olive, persimmon, sorghum, wheats, and other cereals. Many introductions of fruits from temperate zones were brought in from Europe. Finally, by 1898, the Department of Agriculture's activities and interests in the introduction of new plants had become so great that a new unit, the Section of Seed and Plant Introduction, was established. With a modest beginning and an allotment of $2,000, a foundation was laid for an increasing level of activitiy that has had a profound effect on American agriculture.

## 1898-1982

Since 1898, over 400,000 plant introductions have reached the hands of American scientists. More than 200 actual foreign explorations to centers of crop diversity have been undertaken. But numbers alone do not tell the story. Two years after the Section of Seed and Plant Introduction was created, the rediscovery of Mendel's Laws of Inheritance triggered the development of plant breeding as a science. This in turn, gradually, but dramatically, changed plant introduction objectives from the transplanting of crops from other parts of the world into U.S. agriculture to supplying sources of genes to meet crop breeding objectives.

The next very important milestone was the passing of the Research and Marketing Act (PL 733) by the 80th Congress in 1946. This Act authorized funds to the States for cooperative research in which two or more State Agricultural Experiment Stations cooperated to meet common objectives. This "Regional Research Fund" was to be used only for cooperative regional projects recommended by a committee of nine persons, elected by and representing the Directors of the State Agricultural Experiment Stations, and approved by the Secretary of Agriculture. The same Act also authorized the appropriation of funds for use by the Department of Agriculture for cooperative research with the State Agricultural Experiment Stations.

As a result of this Act, the four Regional Plant Introduction Stations, the Interregional Potato Project (IR-1), and the National Seed Storage Laboratory were planned and implemented over the next decade as budgets could be increased to accommodate them.

Throughout the 1960's, budgets for plant germplasm remained level while the purchasing power of those budgets decreased. Then, in 1970, the Southern corn leaf blight epidemic struck. Our corn crop was genetically vulnerable to corn leaf blight because, among other things, a single source of cytoplasm had been utilized in developing a major portion of the corn hybrids. There suddenly appeared a new strain of the fungus pathogen well adapted to that Texas cytoplasm; favorable weather conditions promoted its sweep over the corn crop. The yield of corn dropped an estimated 50 percent or more in some Southern States and 15 percent nationwide.

Thanks to good corn weather the following year (1971) and to heroic efforts by seedsmen, scientists, and farmers, the epidemic that year was mild. The scientific and public reaction to the corn blight epidemic was not so mild. There was real concern that such a disaster could happen in this the World's leading country in agriculture and agricultural science. The National Academy of Sciences responded to this concern and set up a Committee on Genetic Vulnerability of Major Crops to find the answer to the question, "How uniform genetically are other crops upon which the nation depends, and how vulnerable, therefore, are they to epidemics?" The Committee's answer is that most major crops are impressively uniform genetically and impressively vulnerable. The Committee's report was published in 1972 and crystallized a long-standing concern among germplasm biologists that the rescue, preservation, and use of genetic diversity of the world's crop plants, and their wild relatives, was being sadly neglected and rapidly eroded.

Since 1972, there has been a world-wide awakening to the fact that genetic resources are at least of equal importance to the three resources--soil, water, air--that traditionally are referred to in discussing "natural resources." In 1974, the International Board for Plant Genetic Resources (IBPGR) was established by the Consultative Group on International Agricultural Research (CGIAR). In the same year, the U.S. National Plant Germplasm Committee was established and began conceptualizing and organizing a national effort involving the U.S. Department of Agriculture, the State Agricultural Experiment Stations, and commercial interests involved in crop improvement and the seed trade. In 1975, the Secretary of Agriculture appointed the National Plant Genetic Resources Board (NPGRB). The NPGRB was a direct outgrowth of the alarm caused by the southern corn leaf blight.

So we now have a National Plant Germplasm System (NPGS) that provides access to over 400,000 accessions of seed and clonal germplasm. This represents a good start on acquiring and preserving the genetic diversity of economic plants and their wild relatives. The NPGS is pursuing an accelerating program to acquire, maintain, and evaluate for use, as wide as possible a range of genetic diversity of these plants before it is lost forever because of man's adverse impacts on natural environments and changes being made in agricultural patterns and practices.

Plant germplasm has caught the attention of agricultural administrators and national legislators. Now we need to take full advantage of increased budgets and do the best possible job in plant germplasm conservation and use.

## THE NATIONAL PLANT GERMPLASM SYSTEM

The NPGS is designed to provide, on a continuing, long-term basis, the plant genetic diversity needed by farmers and public and private plant scientists to improve productivity of crops and minimize the vulnerability of those crops to biological and environmental stresses. Genetic vulnerability of crops comes into play when an out-of-the-ordinary range of stresses from diseases, insects, drought, or temperature extremes exceeds the crop's range of tolerance or resistance to such factors. The results can vary from noticeable yield reduction in localized areas to disastrous crop failures over very large areas.

An NPGS objective is to broaden the genetic diversity of a crop throughout its production area by having that production come from an array of varieties, all productive but each different from the others in its range of tolerance to one or more potential stresses. This variety and range can reduce the likelihood of epidemic losses.

The major activities of the NPGS are acquisition, maintenance, evaluation, and enhancement of plant germplasm; research on conservation of genetic diversity, monitoring genetic vulnerability, and information management.

## PLANT INTRODUCTION

The Plant Introduction Office (PIO) is part of the Plant Genetics and Germplasm Institute (PGGI) of USDA/ARS at Beltsville, Maryland. It catalogs all incoming accessions, assigns plant inventory (PI) numbers, and distributes PI material to maintenance centers or curators according to established protocols and priorities. No collections are maintained by this office.

The four State/Federal Regional Plant Introduction Stations (RPIS) are at Geneva, New York (NE-9), Experiment, Georgia (S-9), Ames, Iowa (NC-7), and Pullman, Washington (W-6). Each has priority responsibility for maintaining primarily "wild type" and introduced germplasm of many selected crops. The crop responsibility lists may include not only crops maintained at the RPIS but also those under other curators at outlying locations in the region. Should any of the outlying collections come under any jeopardy, it is the responsibility of the Regional Coordinator at the RPIS to take steps that will assure their continued safe maintenance. The Coordinators (all are Federal) have a national responsibility for each species assigned to them. Some of the major crop responsibilities of each station are as follows:

Northeastern Regional Plant Introduction Station, Geneva, New York - Perennial clover, onion, pea, broccoli, and timothy.

Southern Regional Plant Introduction Station, Experiment, Georgia - Cantaloupe, cowpea, millet, peanut, sorghum, and pepper.

North Central Regional Plant Introduction Station, Ames, Iowa - Alfalfa, corn, sweet clover, beets, tomato, and cucumber.

Western Regional Plant Introduction Station, Pullman, Washington - Bean, cabbage, fescue, wheat, grasses, lentils, lettuce, safflower, and chickpeas.

The State Federal Interregional Potato Introduction Station (IR-1) at Sturgeon Bay, Wisconsin, focuses on potato variety development with strong emphasis on germplasm maintenance and upgrading to meet breeders' needs.

## COLLECTIONS

The National Seed Storage Laboratory (NSSL) at Fort Collins, Colorado, is a USDA/ARS facility and the nation's only long-term seed storage facility. The Laboratory maintains plant germplasm as a base collection for the United States and is a backup base collection for many crops in support of the global network of genetic resources centers.

The NSSL base collection is not intended to meet the day-to-day needs of plant breeders and other plant scientists, but rather serves as a reserve stock to prevent loss of germplasm and erosion of genetic diversity. Generally, seed samples in the base collection are also held in a working collection outside the NSSL and therefore are distributed from the NSSL only when unavailable from another source.

The primary objective of the National Clonal Repositories is to maintain and preserve valuable fruit, nut, and other selected crops which are normally propagated by vegetative means.

Twelve separate clonal repositories are planned. Five are now in operation:

Corvallis, Oregon - Pears, filberts, hazelnuts, small fruits, hops, and mint.

Davis California - Grapes, stone fruits, and nuts.

Miami, Florida - Some subtropical and tropical fruits and sugarcane.

Indio, California - Date palm.

Mayaguez Institute of Tropical Agriculture (MITA), Mayaguez, Puerto Rico - Tropical fruits and industrial crops.

The USDA Small Grains Collection is located in the Plant Genetics and Germplasm Institute (PGGI) at Beltsville, Maryland. This working collection contains some 90,000 wheat, barley, oats, rice, rye, and Aegilops accessions. Annually, over 100,000 samples of these accessions are distributed in response to requests from all parts of the world.

## INFORMATION SYSTEM

A feasibility study was conducted during 1976-77 which investigated and identified the need for information management systems in the efficient collection, conservation, distribution, and utilization of plant germplasm in the National Plant Germplasm System.

Agricultural Research Service recognized the critical need for a nationally unified information system to serve the diverse needs of the NPGS. A cooperative agreement with the Laboratory for Information Science in Agriculture (LISA) to develop a computer-based information system led to the formation of the Germplasm Resources Information Project (GRIP).

Analysis of the diverse needs of the NPGS community, its abundant information resources, and the necessary management and use of those resources led to identification of two basic groups of information users within the NPGS - those who supply and those who demand information. "Suppliers" are those who acquire, maintain, and distribute germplasm and data such as curators, and staff of the NSSL and various plant introduction stations. The "demand" group is composed of those who use germplasm and data such as plant breeders, scientists, and researchers. The needs of both groups were identified and small-scale operational prototypes of the system were developed and installed at such NPGS sites as the Regional Plant Introduction Stations. Testing and evaluation of these prototypes (including consideration of user responses and suggestions) then led to the information system's user-oriented design. Among the ways the Information System will serve the supply side will be to provide mechanisms or tools to register accessions as they enter the NPGS, maintain seed inventories, monitor viability of collections, process seed orders, exchange information with other "suppliers," and generate summary reports. The System will allow the demand side to receive information on accessions (including characteristic data and use, and location in the system) as well as requested samples on a timely basis.

The now completed design phase and the beginning of a four-phased implementation will bring the transformation of GRIP to GRIN - the Germplasm Resources Information Network - and continued growth of information management and use in the NPGS.

The Information Network will include not only computer hardware and software, but also people performing specialized tasks, work procedures, and administrative and policy functions. GRIN has been designed to accommodate growth of the NPGS and changing needs brought about by that growth - including additional Information System features and more NPGS facilities and users. This flexibility in fulfilling many critical needs is the key to GRIN's anticipated success and continued evolution.

## ADVISORY GROUPS

The National Plant Genetic Resources Board (NPGRB) provides policy advice directly to the Secretary of Agriculture. The task of the Board is to advise the Secretary on problems, needs, and welfare of the nation's plant genetic resources activities as these impact upon the food production system.

The National Plant Germplasm Committee (NPGC) was established on May 20, 1974, when the Agricultural Research Service (ARS) agreed to a restructuring of the National Coordinating Committee for New Crops, which had been created in 1949 by State Agricultural Experiment Station (SAES) directors. The functions of the NPGC are:

> Provide coordination for the research and service efforts of Federal, State, and industry units engaged in the introduction, preservation, evaluation, and distribution of plant germplasm, through representation of all unit's views by Committee members.
>
> Develop policies for the conduct of the national plant germplasm program and for its relationships to international plant germplasm programs and recommend these to the NPGRB and agencies involved.
>
> Develop research and service proposals and justification for adequate funding of regional and national plant germplasm activities.
>
> The NPGC forum will also be the principal way in which SAES interests can be presented and kept in harmony with Federal interests at a technically informed level.

## THE CROP ADVISORY COMITTEES

The Crop Advisory Committees represent the germplasm user community and provide guidance and coordination to the NPGS on a crop-by-crop basis. There are currently 13 committees.

These Committees are composed of plant scientists drawn from the public sector, both the Federal and State, as well as from the private sector. The curator of each crop serves as a member on his specific crop's committee.

The Crop Advisory Committees have worked on problems regarding exchange of information and have developed minimum lists of descriptors to characterize each crop. They have also developed germplasm evaluation plans. Other pertinent issues addressed by the Committees are:

Germplasm acquisition strategies.

Working collection storage conditions.

Long-term storage conditions.

Regeneration.

Seed distribution guidelines.

Standards for germplasm evaluation.

# WHEAT GERMPLASM

Warren E. Kronstad
Crop Science Department
Oregon State University
Corvallis, Oregon

When mother nature combined three wild grasses to form common wheat, she wisely provided an abundance of different genetic types. This genetic diversity has been enriched over time by the accumulation of favorable mutations and new genetic combinations as a result of hybridization between wheats with different genetic properties. Broadly defined, this diversity can be referred to as germplasm which is the life blood of all crop improvement programs.

## Importance of Genetic Diversity

It is indeed fortunate that this genetic diversity does exist as there are many different environmental stresses under which the wheat plant must grow and provide an economical yield for the producer. Factors such as extremes in temperature, moisture, and other variables including light, length of growing season, sprouting, wind, hail, air pollution, weeds, a multitude of soil problems, and numerous diseases and insect complexes individually or collectively limit maximum yield for specific geographical regions. With the great environmental variation found in the wheat-growing regions of the United States, it should not be surprising that many different varieties are being grown. For example, in 1979, there were 371 different wheat varieties grown commercially. These included 134 representing the hard red winter type, 86 for the hard red spring, 71 soft red winter, and, for the white wheats, 50 common and five club type varieties. In the durum category there were 25 different types. Each of these varieties possesses different attributes which have been developed through breeding.

The need for genetic diversity is further emphasized by the fact that the life expectancy of a wheat variety is limited. A new disease, or genetic change in an existing disease, or some other limiting factor may occur in a very unpredictable manner making current varieties obsolete. Thus we find that plant breeders must continually develop varieties which carry new sources of resistance or tolerance to stay ahead of this never ending battle.

A factor which we frequently overlook is that historically when it comes to wheat varieties, we in the United States have always been borrowers. Wheat did not originate in this country, but rather it is thought to have evolved in the Middle or Near East. Therefore, here in the United States, varieties were first introduced from many different countries for commercial production. Subsequently, different strains of wheat were brought in to be used for hybridizing so that the plant breeders could

genetically tailor make varieties for specific areas of adaptation and market classes.

One can identify landmarks in cereal production in the United States based on varieties which were introduced. For example, Turkey Red gave rise to the hard red winter wheat industry. Another notable example is Red Fife, a variety which was the foundation for the hard red spring wheat industry in this country and Canada. In the Pacific Northwest, the variety Little Club led to the development of this soft white winter wheat production area. Examples where varieties have been used for genetic studies or for developing new varieties can also be clearly identified. Dr. Ernie Sears used the variety Chinese Spring as a means of unlocking many of the genetic and cytogenetic secrets of the wheat plant and thus enabled plant breeders to develop varieties in a much more knowledgeable way. With the introduction of Norin 10 from Japan, Dr. Orville Vogel developed the selection Norin 10-Brevor 14 which gave rise to semi-dwarf wheats. One also must cite Dr. Norman Borlaug who capitalized on the Norin 10-Brevor 14 semi-dwarf characteristic coupled with the genetic factors for daylength insensitivity obtained from varieties such as Gabo to launch the so-called "Green Revolution." There are many other varieties which can be cited for their major contributions to wheat breeding throughout the world. However, there are other materials which have played a very significant part in wheat improvement although their value was not immediately recognized. Plant Introduction, PI 178383, is a strain which originated in Turkey. At first, it appeared to be a disaster as it lodges, is very susceptible to leaf rust, and from every indication would not be a very productive variety or parent. However, when it was systematically evaluated for some of the major diseases, it had resistance to four races of stripe rust, 35 races of common bunt, 10 races of dwarf bunt as well as tolerance to flag smut and snow mold. Thus a nondescript plant introduction was found to have multi-resistance to a number of major diseases and has been extensively utilized in several breeding programs. Triumph is another example. This variety is the result of crosses between four different varieties which included Black Hull, Kanrad, Early Black Hull, and Burbank. These four in themselves were agronomically poor; however when they were crossed, the resulting transgressive segregation produced Triumph which was widely grown in the Midwest for many years. Thus, the contribution that a particular variety or varieties of wheat can make is often not clearly visible. This strongly supports the need of not only collecting materials from throughout the world to increase the available genetic diversity but also the importance of adequately evaluating such materials.

Genetic Erosion

The important role that plant introduction has played in the improvement of wheat in the United States is obvious. As we look to the future, it becomes clear that such genetic diversity must be maintained and even enhanced. There are several factors which are very disturbing regarding the perpetuation of such genetic diversity. The term, genetic erosion, is frequently used to describe a situation which is the result of a number of factors. Old land race varieties are being replaced by newer,

higher yielding varieties. Thus, these land race varieties which are made up of many different genetic types are being lost, and with them, this genetic diversity. The situation is being accentuated as more exacting management practices are required with the newer varieties to obtain the desired yield levels. This in turn requires greater uniformity and less genetic variability within varieties. Furthermore, there are many valuable genetic stocks which are discarded in breeding programs that in fact should be preserved. Often when a breeder retires, much of the genetic information about particular wheat lines and the material itself is lost.

## Germplasm Collection

Thus, it is paramount that a major emphasis be placed on the collecting, preserving, evaluating, and disseminating of information and genetic stocks of wheat if this crop is to continue to be a major source of food for an ever increasing population. Many countries have recognized the importance of developing wheat germplasm centers. Currently 42 countries are listed as having collections. These collections may vary from a few hundred lines to over 70,000. Here in the United States the working germplasm collection located at Beltsville, Maryland has approximately 37,000 different types of wheat. At the long term storage facility at Fort Collins, Colorado, there are approximately 46,200 entries. Even with what appears to be a rather extensive collection of wheat, concerns have surfaced. First of all, are these varieties and lines representative samples? When collections were made were only a few plants identified from a larger population or did those people making the collections take the time to adequately sample the total population of a land race variety or primitive type of wheat? Another concern is with the genetic integrity of the material. If material is collected in Eastern Turkey and then grown out here in the United States over a number of years, does it in fact still represent the original population as collected. Might there have been outcrossing, that is, crosses between different stocks when the materials were grown out to retain their viability? Were errors made during the propagation; were plots mislabeled, or were harvested lines put into the wrong sacks? When dealing with literally thousands of entries, human error is a very real factor. Questions have also been raised concerning the adequacy of the facilities, particularly regarding the germplasm repository in Beltsville, Maryland. The new facility which is currently on the drawing board should receive the highest priority so that no risk is taken in losing the existing collection.

## Evaluation and Dissemination

A point that needs to be emphasized is the utilization of such germplasm. With the advent of the computer, it appears now that a systematic evaluation of the existing germplasm collection must be made and such information be put on the computer for wider distribution to breeders and geneticists throughout the world. This information will not only assist plant breeders in obtaining new sources of resistance or other desired traits, but it would also give direction to those who are currently involved in making additional collections. In terms of the dissemination of

germplasm and information, there are several international nurseries which are effectively doing this at the present time. The oldest is the United States Department of Agriculture's International Rust Nursery where lines are sent out to a number of locations to be evaluated in terms of their reaction patterns in the hope of finding new sources of rust resistance. Each year the University of Nebraska distributes the Winter Wheat Performance Nursery as well as the High Protein-High Lysine Observation Nursery to approximately 68 sites in 34 countries. Certainly CIMMYT (International Maize and Wheat Improvement Program) where the emphasis is placed on spring type bread wheats and durums has an extensive program of germplasm dissemination and evaluation. Nurseries are currently sent to 272 cooperators in 103 countries. At Oregon State University in association with CIMMYT/Mexico, winter and facultative type materials are distributed to the winter wheat areas of the world. These include the International Winter X Spring Screening Nursery and the Winter X Spring Replicated Yield Trial. A total of 110 cooperators in 54 countries are involved in this program. Thus there is a network where information and germplasm can be shared with all major breeding programs throughout the world representing both spring as well as the winter type wheats.

It becomes apparent that as new cultural practices emerge such as intercropping, or multiple cropping or no or minimum tillage systems, that additional limiting factors will be imposed upon the wheat plant. Unless the plant breeder can utilize adequate genetic diversity or germplasm in developing cultivars to fit into these management systems, we are in fact going to see a yield plateau. Also, with wheat being the number one food crop of the world and with an ever increasing hungry population, the role that wheat must play cannot be minimized. Thus it is the responsibility of wheat breeders and geneticists and all those associated with this very vital crop that the future plant breeders will have enough genetic diversity or germplasm to ensure continued development of varieties for future generations.

# POTENTIAL FOR USE OF RELATED SPECIES OF WHEAT

L. W. Briggle
National Research Program Leader for the Small Grain Cereal Crops
Agricultural Research Service, U.S. Department of Agriculture
Beltsville, Maryland

In 1866, the average yield of wheat in the United States was 11.0 bushels per acre. By the year 1900, it was 12.2 bushels per acre. At no time before 1956 did the average yield of wheat reach 20 bushels per acre. Since that same year, it has never been below 20 bushels per acre. It took another 13 years to raise the average yield to 30 bushels--that was accomplished in 1969, and in only one year since that time (1974) has the yield been below 30 bushels. The highest average yield of wheat in the United States--ever, 35.7 bushels per acre--was from the last crop harvested--1982.

There are those who believe we have reached the peak in wheat yields in the United States. We hear much about a yield plateau, or at least oftentimes it is said that we are approaching that yield plateau. I, for one, do not believe those rather pessimistic statements.

The documented record yield of wheat in the United States is 209 bushels per acre. If we accept that as the full potential (and I doubt if that is the real genetic limit), one can readily see that we are now at about 17 percent of that theoretical top yield level. We produce less than one-fifth of a proven possible yield.

We have to realize, however, that nearly all wheat grown in the United States is produced under less than ideal environmental circumstances. Most wheat is grown in the Plains States, where weather is harsh. Some of our wheat area soils are excellent, some are decidedly less so. Many diseases and insects take their toll of that potential crop--from the day it is planted until it is harvested.

Harvest yield is what we measure and quote in our statistical reports, but not all of that wheat ever reaches the consumers' table in the form of bread, cookies, or macaroni. Tremendous losses occur between harvest and consumption as food or feed, or as raw material before being used in an industrial process.

The point I wish to make is that there are several ways that we can increase net production of wheat. Through basic research, hopefully we can eventually develop a more effective plant, one that is more efficient in photosynthesis; one that is more efficient in use of water and fertilizer; one that is more tolerant of temperature stresses. The more we understand the complex basic processes that are involved in plant growth, the more manipulative we can be in making the plant do things our way. Perhaps through such research efforts we can increase the genetic potential yield of the wheat plant.

Another way to increase production is through improved management practices or farming systems, and there are other researchable approaches to be considered. Any method to reduce losses, either before or after harvest, could significantly increase U.S. production.

One procedure that has been used for a long time (and yet we have barely scratched the surface in respect to its potential) is that of crossing related species of wheat to introduce desirable characteristics. There is a tremendous reservoir or source of genetic material available via that route. Vast genetic resources have yet to be exploited.

Genetic resistance is the most efficient and environmentally safe means of disease and insect control. Some pests of wheat can be partially controlled through application of chemicals or through biological control measures, such as release of natural enemies of a destructive insect. So far the principal use of related wheat species has been as a source of resistance to diseases and insects, especially diseases. Unfortunately, wheat pests have genetic systems like their host plants, and can and do undergo changes in their ability to attack wheat. This means that new and different sources of resistance are constantly needed. Even though we have already used some genes for resistance from wild related species, there are many more protective genes "out there."

Most genes used in wheat breeding for resistance to pests have come from various varieties, "land races" (old varieties grown in relatively isolated areas of the World for many years), breeding lines, or from the various Germplasm Collections of wheat. Some people believe that we are nearing exhaustion of resistance genes from cultivated wheats. I would guess that there are several more to be found, but, nevertheless, it would surely be prudent to draw upon the wild species more than we have in the past.

We do have methods and procedures for transfer of genetic traits from related species to wheat, but often the task is difficult. Because of this, we definitely need additional research, primarily in genetics and cytogenetics. Then, looking a long way down the road, hopefully our skill in using the various techniques involved in genetic engineering can provide us with useful tools for transferring desirable alien genes into wheat.

Let us look to a few examples of actual transfer of valuable characters from wild relatives into wheat. In early years the only known source of resistance to stem rust was found in durum and emmer wheats. Although we do not consider durum a wild wheat, both it and emmer (*Triticum dicoccum*) have a different number of chromosomes than common wheat. In spite of sterility and undesirable linkages with other unwanted genes, 'Hope' and 'H44' were the first varieties developed that represent the successful transfer of resistance to stem rust from emmer to common wheat.

Agropyron intermedium, intermediate wheatgrass, has been a particularly useful wild relative. Cauderon describes a step-wise transfer of rust resistance to wheat. (Cauderon, Y., 1977. Alloploidy. pp. 131-143, Interspecific Hybridization in Plant Breeding, Proc. 8th Eucarpia Congress, Madrid). First by crossing the wheatgrass with wheat and then backcrossing to wheat, a stable progeny was selected that contained all the chromosomes of wheat (42) plus 14 from Agropyron intermedium, for a total of 56. Although it was fertile and stable, it was not satisfactory agronomically; yet it was resistant to stem rust, leaf rust, and stripe rust. Further backcrossing and selection resulted in a type with all the wheat chromosomes and only two (one pair) of wheatgrass chromosomes. As the amount of wheatgrass genetic material was reduced, agronomic qualities improved, that is, it became more wheat-like. Finally, through an ingenious technique worked out by E. R. Sears of ARS, USDA, and Ralph Riley of the Cambridge, England Plant Breeding Institute, Cauderon transferred the genes for rust resistance from the Agropyron chromosome to the wheat chromosomes, resulting in an agronomically acceptable wheat with rust resistance.

E. R. Sears' transfer of leaf rust resistance from Aegilops umbellulata to common wheat through an intermediate or "species bridging" step by forming an amphiploid of Triticum dicoccoides X Aegilops umbellulata is the classical model illustrating wide hybridization, amphiploidy, and irradiation, followed by conventional backcrossing and selection to insert a small piece of chromosome from one species into another.

Tables 1 through 4 show a number of related species and the various desirable traits transferred to wheat from each. This list is by no means complete; other transfers have been made or are in various stages of introduction.

Related species represent a tremendously valuable source of useful genes for wheat improvement in the future.

TABLE 1

Some Desirable Characteristics Transferred from the Wild _Triticum_ Species

| DONOR SPECIES | CHARACTERISTIC TRANSFERRED |
|---|---|
| _Triticum monococcum_ | Resistance to common smut, dwarf smut, powdery mildew |
| _Triticum dicoccum_ | Resistance to stem rust and powdery mildew |
| _Triticum timopheevi_ | Resistance to stem rust and powdery mildew, male sterility, fertility restoration |
| _Triticum dicoccoides_ | Resistance to leaf rust, stripe rust, and powdery mildew; high grain protein, drought tolerance |

TABLE 2

Some Desirable Characteristics Transferred to Wheat from Wild *Aegilops* Species

| DONOR SPECIES | CHARACTERISTIC TRANSFERRED |
|---|---|
| *Aegilops squarrosa* (*Triticum tauschii*) | Resistance to leaf rust, Hessian fly, and Greenbug |
| *Aegilops umbellulata* | Resistance to leaf rust; short plant height |
| *Aegilops comosa* | Resistance to stripe rust |
| *Aegilops variabilis* | Short plant height, resistance to cereal cyst nematode |
| *Aegilops speltoides* | Resistance to stem rust |
| *Aegilops longissima* | Early maturity, large kernels, high tillering |

TABLE 3

Some Desirable Characteristics Transferred from *Agropyron* (Wheatgrass) Species

| DONOR SPECIES | CHARACTERISTIC TRANSFERRED |
|---|---|
| *Agropyron elongatum* | Resistance to stem rust, leaf rust, stripe rust, and *Aceria tulipae* (wheat curl mite which transmits Wheat Streak Mosaic Virus), tolerance to Yellow Dwarf Virus |
| *Agropyron intermedium* | Resistance to stem rust, leaf rust, stripe rust, immunity to Wheat Streak Mosaic Virus |
| *Agropyron glaucum* | Resistance to leaf rust |

TABLE 4

Some Desirable Characteristics Transferred from Rye

| DONOR SPECIES | CHARACTERISTIC TRANSFERRED |
|---|---|
| *Secale cereale* (rye) | Resistance to stem rust, leaf rust, stripe rust, powdery mildew, Hessian fly, and Greenbug; short plant height |

# USDA SMALL GRAIN COLLECTION

D.H. Smith, Jr., Curator
USDA Small Grain Collection,
Agricultural Research Service,
Beltsville, Maryland

The USDA collection of small grains (wheat, barley, rice, oats, rye, triticale, Aegilops and their related species) is an invaluable resource for current and future use to improve yield, quality, and other characteristics in cereals. Numerous examples of benefits from using accessions in the collection in breeding programs can be cited, such as insect and disease resistance, high protein, improved amino acid ratios, and tolerance to aluminum toxicity. The collection, maintenance, distribution, and evaluation of cereal germplasm are ongoing activities of the USDA. Since the organization of the Seed and Plant Introduction Office in 1898 there has been a continuing program to: (a) collect and maintain plant material that may contribute either directly or indirectly to crop improvement; (b) establish reliable procedures to preclude the inadvertent introduction of new diseases, insects and weeds; and (c) distribute useful introductions for use in plant breeding and other research programs. Increased support for the USDA Small Grain Collection was provided by a special appropriation of the Research and Marketing Act of 1946. This additional funding was used to grow introductions in quarantine, insure the maintenance of viable seed, accumulate data on adaptation and reaction to pests, catalogue other information of use in improving the crop, and fill requests for seed from researchers.

Our current holdings make the collection one of the two largest in the world; the other is at the N.I. Vavilov Institute, USSR. We now have over 37,000 wheats, 25,000 barleys, 19,000 oats, 18,000 rices, 2,000 ryes, 900 triticales and 300 Aegilops. Included in these groups are accessions of related species, both domesticated and wild. These accessions have been received from plant exploration, exchanges with other collections, and from individual research workers. The major sources have been Asia, Europe, the United States, Australia and New Zealand, with fewer introductions received from Africa, South and Central America, Mexico, and Canada. Distribution of small samples, usually five grams, is made upon request at no charge. Requests come from both foreign and domestic sources. In a given year seed may be distributed to as many as 70 different countries.

The maintenance of seed stocks is expensive, but much less expensive than the concerted effort needed to locate specific seed sources that have been lost or discarded from breeding programs. Furthermore, the original genetic source may have disappeared in the country or region where it was collected. Changing agricultural practices, including the adoption and widespread use of improved

varieties, have reduced the genetic variability that was once found in or near certain major centers of origin or diversity. In addition to agricultural development, intensive grazing, population pressure, and industrial growth have contributed to the loss of natural plant populations, including primitive forms and wild relatives that serve as a potential reservoir of diversity.

Collections of germplasm fall into two major categories, working collections and base collections. The USDA Small Grain Collection at Beltsville is a working collection. We insure that all seed stocks are documented, held under appropriate storage condtions, evaluated, and made available for use. In contrast, base collections are stored under conditions enhancing long-term conservation. Seed in base collections may duplicate working collections, but accessions are released only when they are not available from other sources. Seed moves from working collections to long-term storage.

One goal of the USDA Small Grain Collection is to increase genetic diversity in small grain cultivars. This is accomplished through collection, maintenance, evaluation, and distribution of germplasm suited to the needs of research workers. Documentation and dissemination of evaluation data is also an important means of achieving this goal. Assembling and maintaining germplasm received from plant exploration and seed exchanges with research workers in the United States and other countries are major undertakings. Procedures followed in handling our small grain collection illustrate both the complexity of the task and the need for cooperation and good coordination among private, state, regional, national, and international organizations. Accessions include mutations, synthesized species, and lines that represent new or unusual gene combinations.

Seed of accessions received from foreign sources is inspected and fumigated to kill insects. They are then assigned a Plant Inventory (PI) number, and available information such as name, origin, and any special characteristics are documented. Seed is increased in a detention nursery at Mesa, Arizona. New accessions from domestic sources are also documented and assigned PI numbers, and entered directly into the collection or increased as needed at Mesa, Arizona, Aberdeen, Idaho or El Centro, California.

Each accession is observed for evidence of such seedborne diseases as the smuts and certain viruses. The nurseries are isolated from major grain-growing areas, so that latent plant diseases brought in with imported seed samples can be intercepted without endangering U.S. crops. Contaminated accessions are treated and replanted. Those

accessions are discarded if there is evidence that treatment did not eliminate the disease.

About 400 grams of seed of each entry grown in the nurseries are returned to Beltsville for inclusion in the working collection. Seed is stored at 10° C and 40% relative humidity. Five-gram samples are distributed without charge to public and private research workers for experimental purposes. Requests may range from a single item to a complete set of one of the crop collections. In 1982 we received 456 requests which resulted in our sending out approximately 117,000 seed samples.

An automated information system is used to store and retrieve data of the following characteristics: plant growth and growth habit; color of the kernels, straw, chaff, and awns; reactions to diseases and insect pests such as rusts, smuts, viruses, greenbug, cereal leaf beetle, Hessian fly, and sawfly. This system is used to prepare lists of accessions to accompany seed shipments and special listings of all or various portions of the collection that possess certain traits in common.

# BREEDING FOR RESISTANCE TO WHEAT RUSTS

R. H. Busch
Agricultural Research Service
U. S. Department of Agriculture
and
University of Minnesota
St. Paul, MN

Three different rusts attack wheat in the United States: stem rust, leaf rust, and stripe rust. Stem rust has been the most devastating rust, primarily in the upper midwest, although both leaf and stripe rust may cause significant losses. Through the long term effort of combining major resistance genes into varieties, determining the specific pathogenicity of stem rust, providing diversity of resistance genes in different regions, and eradicating the alternate host (barberry), losses due to stem rust have been virtually eliminated in the past 25 years. The pathogen remains a constant potential threat; but as long as effective cooperative research continues among wheat breeders, geneticists, and plant pathologists, this rust appears to be under effective control by use of resistant varieties.

Less total research effort has been spent on resistance to leaf and stripe rust than on stem rust because their epidemics have caused less widespread loss. Nevertheless, significant effort has been made and major progress has been achieved with varietal resistance to these rusts. The resistance obtained usually has not been as long lasting as it has been for stem rust. Emphasis on incorporating different genes for resistance and selection for general resistance has increased for stem, leaf, and stripe rusts. However, shifts in prevalent races of leaf and stripe rust and inadequate knowledge about these pathogens require further and continuing research.

# RESISTANCE TO HESSIAN FLY AND GREENBUG

J. H. Hatchett
Agricultural Research Service,
U.S. Department of Agriculture and
Department of Entomology, Kansas State University
Manhattan, Kansas

The Hessian fly and greenbug are the most damaging insect pests of wheat in the United States. Breeding wheat varieties resistant to Hessian fly and greenbug has the greatest potential for reducing grain losses. Research scientists of the Agricultural Research Service, USDA, Agricultural Experiment Stations, and private industry in 14 States are working toward the development of wheat varieties that resist attack by the two insects.

## Hessian Fly

The Hessian fly is found throughout the major wheat-producing areas of the United States, although the most serious infestations have occurred in Midwestern and Great Plains States. The most effective control for the Hessian fly has been the use of resistant varieties of wheat. Breeding Hessian fly-resistant wheats has been continuous since the 1940's. As a result, 58 resistant varieties have been developed for commercial production. In 1979 about 21 million acres of wheat were seeded to Hessian fly-resistant varieties. These varieties provided protection for about 90% of the eastern soft wheat acreage and 36% of the hard wheat acreage.

Although resistant wheat varieties have reduced Hessian fly damage during the last 25 years, breeding for dependable resistance has been complicated because of the development of host-specific biotypes that can attack resistant varieties. These genetic adaptations of the insect to changes in resistance of wheat were anticipated. Thus, wheat varieties having different biotype-specific resistance have been developed to prevent damage by new biotypes. Thirteen major genes for resistance to Hessian fly are being used in breeding resistant wheats.

The strategy for management of these genes in wheat breeding programs has been the sequential release of varieties with major genes for resistance. When resistant varieties are grown widely for several years and there is evidence of biotype development, varieties with new biotype-specific resistance are released. This strategy has provided effective use of major genes. Biotypes have not developed sufficiently rapidly for resistant varieties to lose effective control. On the basis of present knowledge of genetic variation for resistance to Hessian fly in wheats, it is likely that resistance will be maintained in the future, as new genes are identified and bred into new wheat varieties.

Greenbug

The greenbug is a major pest of small grains and sorghum in the Great Plains, Northwestern, and Southeastern States. Outbreaks of greenbug on wheat have occurred more often in the southern and central Great Plains and the Pacific Northwest. Research to locate greenbug resistance in wheat and other small grains and breeding greenbug-resistant wheats began in the 1950's. The resistance mechanism sought has been primarily plant tolerance to feeding damage. Single gene sources of resistance have been identified and transferred to adapted wheat germplasm although resistant varieties are not yet available for commercial production. During the last 20 years, varietal development of greenbug-resistant wheat has suffered two major setbacks when resistance was overcome by virulent biotypes. The sudden development of virulent biotypes in the absence of selection by resistant varieties indicates a highly unstable host virulence system in the greenbug.

Additional single-gene sources of resistance to the greenbug have been identified in different strains of *Triticum tauschii*, a wild species of wheat. These genes are effective against the known greenbug biotypes and have been successfully transferred to common wheat. Wheat germplasms having greenbug resistance derived from *T. tauschii* have been released and are now being used in developing varieties resistant to virulent biotypes. The resistance of *T. tauschii* represents diverse genetic sources and may provide more durable resistance for breeding greenbug-resistant wheats in the future. Also, the use of these genes in different combinations rather than singly may provide stability for resistance should the greenbug undergo further genetic changes that increase its virulence.

# RESISTANCE TO VIRUSES

C. M. Brown
Professor of Agronomy, University of Illinois
Urbana, Illinois

Over 30 viruses are known to infect and cause yield losses of wheat. These viruses are world-wide in distribution and they are transmitted by fungi, mites, leafhoppers, plant hoppers, and aphids as major vectors. Although virus damage to wheat can sometimes be reduced by cultural, chemical, and other means to control the vector or the virus, breeding of resistant varieties continues to be the most effective control method. Research scientists in the public and private sectors throughout the world continue to develop varieties that are resistant to the major virus diseases.

Breeding for resistance to the viruses is complicated by the fact that the breeder must deal with the interrelationships among the wheat host, the virus, and the vector, each with its unique genetic composition. In order to devise a successful program of breeding for resistance to a particular virus disease, the breeder must have knowledge about the epidemiology of the disease. It is especially important to know how the virus spreads, its specific vectors, and the relationship between the virus and its vectors. It is also necessary to know of or develop ways whereby the virus can be transmitted easily for use in screening and selection tests. Obtaining and applying this information in a breeding program requires the cooperative efforts of several disciplines, including but not limited to plant breeding, virology, and entomology.

A successful breeding program for resistance to wheat viruses must comprise the following:

1) Heritable and stable sources of germplasm resistant to the virus, to the vector, or to both.
2) An efficient method of transmitting the disease for screening trials.
3) A suitable and rapid method for distinguishing between resistant and susceptible plants or progenies.

If these conditions are met, it is then relatively simple for the breeder to devise a strategy for developing resistant varieties. With this background it appears appropriate to consider the present status of breeding programs with reference to several of our potentially most damaging virus diseases.

Barley Yellow Dwarf (BYD)

BYD is vectored by 18 different species of aphids. Wheat varieties and germplasm lines have been found to differ in levels of tolerance but immunity or high levels of resistance have not been found in common hexaploid wheat. Several *Agrotriticum* lines from Oklahoma have shown a relatively high level of tolerance. Based on past experience with other crops, particularly oats, it should be possible to develop higher levels of tolerance via transgressive segregation. Suitable, but time-consuming and expensive transmission and screening methods are in current use in several programs in the United States.

Wheat Streak Mosaic (WSM)

WSM is vectored by the wheat curl mite. A moderate level of tolerance to WSM has been found in several commercial varieties such as Eagle and Scout. Kansas workers and others have found excellent sources of resistance to the virus and to the vector in some germplasm lines derived from wheat-*Agropyron* and wheat-rye crosses. These excellent sources of resistance are more difficult to utilize in a breeding program, but with time and effort will be used to develop resistant varieties. Mechanical transmission and suitable screening methods have been developed and are used by wheat breeders.

Soilborne Wheat Mosaic (SBWM)

SBWM is vectored by a fungus, *Polymyxa graminis*. Excellent resistance to SBWM is available in common hexaploid varieties of wheat. Screening for resistance is accomplished by growing progenies in SBWM-infested soil. Breeding programs for resistance to SBWM have been extremely successful and in some areas of the United States most of the widely grown varieties are resistant.

Wheat Spindle Streak Mosaic (WSSM)

WSSM is vectored by the same fungus (*Polymyxa graminis*) as SBWM. Resistance to WSSM has been discovered in several wheat varieties and several wheat varieties and germplasm lines have combined resistance to WSSM and SBWM. Similar methods are used in screening for resistance to the two viruses.

Thus, at least for the present, most of the necessary ingredients for developing varieties resistant to the important virus diseases of wheat are available. Although different strains of the viruses do exist and may change from time to time, many of the virus-resistant sources have remained effective for a relatively long time. However, we must strive to learn more about the important virus diseases of wheat and continue to increase our efforts to locate, develop, preserve, and utilize new and improved sources of virus resistance in our breeding programs.

# RESISTANCE TO WHEAT SMUTS

R. J. Metzger
Agricultural Research Service
U. S. Department of Agriculture
and
Oregon State University
Corvallis, OR

Smut and/or bunt are the common names for the black spores (seeds) produced by any one of five different fungi that invade susceptible wheat plants. Spores of common bunt (*Tilletia caries* and *T. foetida*), dwarf bunt (TCK or *T. controversa*), loose smut (*Ustilago tritici*), and Karnal bunt (*T. indica*) are produced in the wheat spike in lieu of grains. Flag smut spores (*Urocystis tritici*) are produced on the leaf sheaths and blades.

In favorable environments the quantity of spores produced in a given field is determined by the effectiveness of the genetic resistance carried by the variety and/or the fungicide used to treat the seeds. Fungicides provide acceptable levels of protection to the fungi that cause common bunt, loose smut, and flag smut. They are less effective against the fungi that cause dwarf bunt (TCK) and Karnal bunt because of soilborne sources of inoculum. Fungicides are not commonly used in the less developed countries because of costs and fear that treated grain may be consumed by humans and/or animals. Such countries must depend on the development of varieties carrying genetic resistance to the casual organisms.

The same genes govern resistance to the fungi that cause common and dwarf bunt (TCK). Acceptable levels of genetic resistance have been obtained from the world collection of wheats maintained by ARS-USDA, Beltsville, Maryland. Since 1954, more than 25,000 wheat introductions have been screened for resistance to common bunt, including 2,600 individual head selections collected in Eastern Turkey in 1979. Eight previously unknown genes have been identified that can be used in various combinations with the seven genes identified prior to 1954 by wheat breeders to develop varieties resistant, but not immune, to both common and dwarf bunt (TCK).

Acceptable levels of genetic resistance to loose smut and flag smut are available; but in developed countries, fungicides are usually used to maintain control. In the less developed countries both diseases cause significant economic losses. Varieties resistant to both diseases are needed.

Karnal bunt has spread rapidly throughout northern India and adjacent countries in recent years. Serious economic losses occurred in both 1981 and 1982. Genetic resistance has not been found among the thousands of wheats tested. Fungicides, in current use, are ineffective against soilborne sources of inoculum. Scientists are currently in the process of screening additional selections of wheat obtained from the world collection for resistance.

# ROOT AND CROWN DISEASES: MAJOR COST FACTORS AND YIELD CONSTRAINTS FOR WHEAT

R. James Cook
Agricultural Research Service, U. S. Department of Agriculture, and Washington State University, Pullman, Washington

The productivity of wheat depends on healthy roots for the uptake of nutrients and water for manufacture of essential growth hormones and other factors transported to the leaves and spikes (heads). Unfortunately, while the importance of roots to overall plant performance and productivity is obvious and widely accepted, the damage to roots caused by soilborne pathogens, being below ground and hence out of sight, is almost always ignored except in the most acute cases of root and crown rot.

Wheat has a fibrous root system made up of many main roots, lateral (branch) roots connected to these main roots, and commonly branch rootlets connected to the laterals. A healthy root system may have several orders of branching. Each root and rootlet terminates in a tip with root hairs. Most of the nutrient uptake and the manufacture of growth factors takes place at these root tips. Many essential mineral nutrients (for example, P, K, and trace nutrients) move slowly or not at all toward the root and thus the root must grow toward the nutrient. This is accomplished by the millions upon millions of root tips on each root system that explores the soil. Much of the nutrient uptake occurs in the top layer of soil where root pathogens are also most concentrated. These pathogens include root "nibblers", producers of root toxins, and true parasites that invade and rot the juvenile tips. Such damage becomes a serious constraint on the ability of roots to perform their essential functions for the tops.

Root infections may remain confined to the roots. Plants with damaged roots look and grow like plants with inadequate mineral nutrients--small in stature, poorly tillered, and with narrow leaves that lack a healthy green color. Some root pathogens also grow upward into the stem base and rot the crown (area where stems are attached to one another). Water movement from the roots to the tops is then restricted and such plants usually die prematurely when they are subjected to hot weather and drying winds (giving the white heads symptom with shriveled grain).

The root pathogens important on wheat are mainly soilborne fungi, but pathogenic nematodes and bacteria are also involved. Several species of _Pythium_ attack and rot the fine feeder rootlets of wheat. _Pythium_ root rot is confined to roots and rootlets and does not develop into a crown rot or cause premature plant blight. Fungi responsible for snow molds (_Typhula idahoensis_, _T. incarnata_, and _Fusarium nivale_) also may cause crown rot and some cause root rot of winter wheat. Damage from these fungi is usually greatest on wheat subjected to cold stress or buried for long periods beneath snow with unfrozen soil. _Gaeumannomyces graminis_ var. _tritici_, cause of

take-all, infects the roots first and then spreads upward into the crown. Infection by this fungus is favored by wet soil (such as provided by pivot irrigation) but the plants usually do not die prematurely until hot weather occurs. Fusarium roseum 'Culmorum' and 'Graminearum' likewise usually begin by infecting the roots and then spread into the crown. These fungi are most pathogenic to wheat when soils are relatively dry and the plants are subjected to water stress. Helminthosporium sativum infects the roots but more commonly the subcrown internode and may then grow into the crown. This fungus is also favored by dry soils and plant water stress. Cephalosporium gramineum cause of Cephalosporium stripe, enters the roots through wounds and then invades and plugs the vascular system, causing stunting and premature blight. Cercosporella herpotrichoides (cause of eyespot foot rot) and Rhizoctonia cerealis (cause of sharp eyespot) invades the stems at or slightly below the soil surface and causes deep lesions and even girdling and breaking of the stem. Pathogenic nematodes and bacteria are not included in the list since little is known of their importance and environmental requirement. Table 1 gives a summary of the pathogens responsible for root and crown rots of wheat and methods of control.

Wheat production in Washington State would have been 15-20% (approximately 20-30 million bushels) greater in each of the last 8 years, were it not for the damage caused by the root and crown diseases. This loss is proportionally as great as the 15% loss estimated from southern leaf blight on corn in the epidemic year of 1970. The main causes of this loss have been Cephalosporium stripe, Cercosporella foot rot, Fusarium foot rot, take-all, and Pythium root rot. While the losses are a matter of record in Washington State, and in the other Pacific Northwest States, recent studies indicate that losses of similar magnitude also occur for wheat in some areas in the Central Great Plains States and in the Eastern United States in many or most years. The responsible pathogens all are favored by the trend away from crop rotation and many or most are also favored by reduced tillage.

The loss from root disease has been demonstrated in the Pacific Northwest by experiments with soil fumigation or other soil treatments--unique research techniques that eliminate or inhibit root pathogens. The full biological potential of the variety set by climate, weather, soil and agronomic inputs is then revealed. For example, in 1982, the yield of 'Daws' winter wheat in a typical pea-wheat rotation near Pullman was increased 38 bu/A, from 63 to about 101 bu/A, by fumigation of the soil with methyl bromide, yet the fertilizer, herbicide, tillage, and planting dates were the same for the treated and untreated areas. In 1980, the average yield increase for winter wheats was 20 bu/A for six trials in eastern Washington where soils were fumigated. Soil fumigation trials in Idaho, Oregon, Montana, Kansas, and Pennsylvania have produced similar yield responses. In eastern Washington and adjacent northern Idaho, approximately 25 fumigation experiments since 1974 have produced an average increase of more than 15%.

Significantly, the plants in the nonfumigated soils would be considered normal without the comparisons of wheat in fumigated soil. The plants are larger, more vigorous and greener where the soil had been freed of root pathogens by fumigation, and the response is apparent throughout the growing season.

Growers often and unknowingly attempt to compensate for root damage by applying more fertilizer. Improvements in root health could reduce the amount of fertilizer needed to produce a wheat crop. Plants with damaged roots are also less competitive with weeds, which increases the need for herbicides. Since the trend is toward less tillage and less crop rotation, the problem is likely to worsen. Fumigation is a research tool and is not acceptable as a commercial practice. Methods must be found to achieve the same degree of root and crown health without fumigation. The use of beneficial root colonizing soil microorganisms offers one means to protect roots against pathogens and is presently under study by both private and public supported research groups. Solving the root health problem for wheat requires long-term basic research, but promises to provide the next significant increase in yield and to also reduce the need for fertilizer, tillage, and herbicides.

Table 1. Root- and Crown-infecting Fungi of Wheat: Kinds of damage, favorable environment and management, and methods of control.

| Pathogen | Form of Damage | Favorable Environment | Favorable Management | Control |
|---|---|---|---|---|
| *Cephalosporium gramineum* | Plugging of the vascular system in roots and stems. Plant dies after heading. | Cool, wet, poorly drained slightly acid soil where freezing and heaving occur; important on winter wheat only. | Winter wheat grown every year or every other year in the same field; and reduced tillage. | Three-year rotations. Avoid highly susceptible varieties. |
| *Cercosporella herpotrichoides* | Eyespot lesion on the stem just above the soil line; stems girdled and break off, causing white heads and lodging. | Cool (5-15°C) rainy weather typical of Nov-Dec and Feb-April in eastern Washington. | Early seeding of winter wheat on fallow, or in 18-24 inch annual rainfall, wheat seeded early after peas or lentils. | Delay seeding date; apply fungicide in early spring. |
| *Fusarium roseum* 'Culmorum' and 'Graminearum' | Root and crown rot with brown decay 1-3 internodes up the stem. Plants may die at any stage, but usually after heading, resulting in white heads. | Warm, dry soil conditions and plant water stress. | Early seeding on fallow with high rates of nitrogen fertilizer. | Delay seeding date; reduce rates of nitrogen to avoid water stress of the wheat, and plant drought-tolerant cultivars. |
| *Gaeumannomyces graminis* var. *tritici* | Root and crown rot with blackened stem base; plants may die at any stage, usually in patches, and usually after heading, resulting in white heads. | Cool (5-20°C) moist alkaline soils. | Liming the soil, pivot irrigation, reduced tillage, and wheat seeded two or more consecutive years in the same field. | Avoid growing wheat or barley 2 consecutive years in the same field, or stay with monoculture (disease will eventually decline); maintain good soil fertility (NPK) and use some form of tillage. |
| *Pythium* spp., including *aristosporum*, *ultimum* var. *ultimum* and var. *sporangiferum* and *torulosum* | Seed decay, seedling blight and root rot. Plants stunted or unthrifty. | Cool, moist or waterlogged soil with abundant straw residue on or near the soil or mixed with the surface soil. | Late seeding of winter wheat with reduced tillage. | Avoid late seeding in wet, poorly prepared seed beds. Some potential for partial control by seed treatment fungicides. |
| *Rhizoctonia cerealis* | Sharp eyespot lesions on stems below, at, or above the soil surface. Affects plant at any stage. | Cool, wet soil conditions. | Reduced tillage and winter wheat grown every year or every other year in the same field. Sometimes more prevalent in fields sprayed with fungicide to control *Cercosporella* foot rot. | Minor problem so far, and no control measures have been necessary. |
| *Helminthosporium sativum* | Rot of roots and subcrown internodes; brown to black discoloration of crowns may result in premature plant death with shriveled grain. | Warm, dry soil conditions and plant water stress. | Wheat-fallow or other rotations that permit early seeding in warm, dry seedbeds. | Delay the seeding date of winter wheat to avoid plant water stress; 3-year rotations. |

CONTROL OF FOLIAR DISEASES IN WHEAT WITH FUNGICIDES

J. R. James
Agricultural Division, CIBA-GEIGY Corporation,
Greensboro, North Carolina

Wheat foliar diseases are primarily controlled by genetic resistance in the United States, with currently less than 1% of the acreage receiving fungicide applications. However, in many cereal-growing regions foliar diseases often significantly reduce yields because genetic resistance is lacking or new races of wheat pathogens have evolved, which can infect previously resistant varieties. USDA crop loss estimates for the period 1951 to 1960 indicate that 14% of wheat yields are lost annually to diseases (Table 1). Of this 14%, rust, Septoria, leaf spot and glume blotch, and powdery mildew account for 7.9%.

Table 1. Estimated loss of U.S. wheat yield due to disease for the period 1951-1960.

| Disease | % Yield loss | Disease | % Yield loss |
|---|---|---|---|
| Stem Rust | 4.0 | Pseudocercosporella Foot Rot | 0.6 |
| Leaf Rust | 2.5 | Scab (*Fusarium* spp.) | 0.6 |
| Root Rots | 1.0 | Soilborne Mosaic | 0.5 |
| Septoria Leaf Spot | | Common Bunt | 0.4 |
| and Glume Blotch | 1.0 | Take-all | 0.2 |
| Wheat Streak Mosaic | 1.0 | Bacterial Diseases | 0.1 |
| Loose Smut | 0.8 | Other Diseases | 1.0 |

Because these figures represent 1951 to 1960 data, the relative importance of certain diseases may have changed because of shifts in wheat acreage and cultural practices. For example, during 1979-1981, ceral productions in the Southeastern States of Mississippi, Alabama and Georgia increased over 600%. In these areas, disease such as powdery mildew, rust, and Septoria leaf spot and glume blotch are more common because environmental conditions are more conducive for disease development.

In contrast to the United States, foliar fungicides are routinely integrated into intensive cereal management in Europe. Yields in Europe are maximized per unit of land by more intensive use of fertilizers, fungicides, and growth regulators. Cereal yields in Europe are commonly 90-150 bu/A. Generally it is recognized that fungicide use increases yields by approximately 20-25% under normal disease situations.

Use of foliar fungicides in the United States may be limited because primarily only protectant compounds with a narrow spectrum of activity such as the dithiocarbamates are currently registered. Recently, several new sterol-inhibiting fungicides of triazole chemistry were introduced into the European cereal market. Tilt® (CGA-64250) is one such compound being developed by CIBA-GEIGY. Tilt was commercially introduced into Europe in 1980 and is currently being applied to a major portion of the cereal acreage.

Tilt has been tested extensively in the United States and has been shown to be a broad spectrum fungicide which provides control of major foliar and ear pathogens such as yellow rust (caused by *Puccinia striiformis*), stem rust (caused by *Puccinia graminis* f. sp. *tritici*), leaf rust (caused by *Puccinia recondita*), powdery mildew (caused by *Erysiphe graminis*), Septoria leaf spot (caused by *Septoria tritici* and *S. nodorum*) and glume blotch (caused by *S. nodorum*).

Potential yields of wheat are based on three growth parameters. These are (i) the number of tillers, (ii) the number of grains/head and (iii) grain weight. The most critical wheat growth stages for development of these three parameters are 1) number of tillers - stages 5-7, 2) number of grains/head - stages 7-8, and 3) grain weight - stages 10.3-11.3. Although all are important, number of grains per head and grain weight could be considered most important in terms of timing fungicide applications. Results from field trials have shown that two applications of Tilt applied at stage 7-8 and 10.3-10.5 have consistently provided good disease control and yield increase. This protectant schedule protects the flag leaf where the majority of photosynthates for grain weight are produced and also protects the ear from diseases such as powdery mildew and glume blotch.

Tilt is also a systemic compound with curative properties. The curative activity of Tilt allows for better timing of fungicide applications following disease appearance. This is advantageous over protective fungicides which must be applied before infection, which sometimes results in little benefit because the disease may fail to develop. The current recommended use rate and application schedule for Tilt are outlined in Table 2. Because of differences in disease pressure, schedule modifications may be necessary in certain areas. In some years, one application of Tilt may provide adequate crop protection.

Table 2. Protective and curative application schedule for Tilt 3.6E on wheat

| Schedule | Application No. | Rate (g ai/A) | Timing |
|---|---|---|---|
| 1. Protective | 1 | 50 | Stage 7-8 |
| | 2 | 50 | Stage 10.3 to 10.5 |
| 2. Curative | 1 | 50 | Appearance of disease (<5%) at stage 7-8 |
| | 2 | 50 | 3-4 weeks after the first application if: (i) new disease appears (ii) disease pressure continues (iii) glume blotch is expected |

Tilt has been tested extensively for control of major foliar diseases of wheat. The following is a discussion of representative efficacy and yield data obtained during 1982. The expected yield benefits from Tilt applications depend on the time of appearance and severity of diseases during the growing season. Other parameters such as culture practices, varietal resistance, and climate affect the yield potential of wheat; therefore, yield increases are not always observed. These trials were conducted under moderate to heavy disease pressure.

In trials conducted in Pennsylvania and Alabama (Tables 3 and 4), Tilt applied at 50 g ai/A provided good powdery mildew control and significantly ($\underline{P}$ = 0.05) increased wheat yields. In the Pennsylvania trial two applications of Tilt at stages 7 and 10 gave complete control of powdery mildew, while one application at 75 g ai/A resulted in 1% disease. Check plots had a disease rating of 56.2% powdery mildew. Both Tilt treatments also provided excellent Septoria leaf blight control. Yields were 59.19, 57.52, and 45.04 bu/A in plots which received one application at 75 g ai/A, two applications at 50 g ai/A and the check plot, respectively. In the trial conducted in Alabama (Table 4) under heavy powdery mildew pressure, plots treated with Tilt at 50 g ai/A at stage 7 and 10.1 yielded 36.1 bu/A compound to 16.8 bu/A in the check.

In two trials conducted for Septoria control in Maryland (Tables 5 and 6), Tilt applied at 50 g ai/A at stage 8 and 10.1 significantly decreased the incidence of Septoria leaf blight and glume blotch and correspondingly increased yields.

Representative rust control data were those obtained in university trials by Dr. L. Anzalone (Louisiana State University) and Dr. R. Powelson (Oregon State University). Dr. L. Anzalone's trial was conducted on the varieties Arthur 71, McNair 1003, Southern Belle, and Coker 6815 (Table 7). Tilt provided excellent control of leaf rust in all varieties and significantly ($\underline{P}$ = 0.05)

increased yields in Arthur 71, McNace 1003, and Southern Belle. Tilt numerically increased yields over the untreated check in Coker 6815 (37.1 vs 62.0 bu/A); however, this was not significant at the P = 0.05 level. Arthur 71 and McNair 1003 are susceptible to rust. Southern Belle and Coker 6815 are described as resistant; however, new races of leaf rust have evolved which are more pathogenic on Coker 6815.

In Dr. R. Powelson's trial, Tilt applied at 50 g ai/A at growth stages 7 and 9 provided excellent control of stripe rust. Tilt plots of 'Orin' wheat received a disease rating of 0.04 compared with 40% in the check. Orin yields were also significantly higher (P = 0.05) than the check (4.0 vs 3.17 metric tons/A). Also included in Dr. R. Powelson's trial were the varieties Stephens and Yamhill which have more rust resistance than Orin. Under the disease pressure experienced during 1982, no yield response was observed with these varieties.

Table 3. Control of powdery mildew and Septoria leaf blight in winter wheat with foliar applications of Tilt - C. Buchholz (PA).

| | | | Disease Rating | | |
|---|---|---|---|---|---|
| Treatment | Rate (g ai/A) | Schedule | % Powdery Mildew | % Septoria | Yield (bu/A)[a] |
| 1. Tilt | 75 | 10 | 1.0 | 2.0 | 59.19a |
| 2. Tilt | 50 | 7 + 10 | 0 | 1.71 | 57.52a |
| 3. Check | -- | -- | 52.6 | 48.13 | 45.04b |

[a] Yields with different letters are significantly different at the P = 0.05 level.

Table 4. Control of powdery mildew in winter wheat with foliar applications of Tilt - M. Hammond (AL).

| Treatment | Rate (g ai/A) | Schedule | Powdery Mildew rating | Yield (bu/A)[a] |
|---|---|---|---|---|
| Tilt | 50 | 7 + 10.1 | 2.5 | 36.1a |
| Check | -- | | 4.3 | 16.8b |

[a] Yields with different letters are significantly different at the P = 0.05 level.

Table 5. Control of Septoria leaf blight and glume blotch in winter wheat with foliar applications of Tilt - G. Schnappinger (MD).

| Treatment | Rate (g ai/A) | Schedule | Septoria leaf blight | Glume blotch | Yield (bu/A) |
|---|---|---|---|---|---|
| Tilt | 50 | 8 + 10.1 | 3.2 | 4.8 | 55.9 |
| Check | -- | -- | 50.7 | 18.3 | 51.2 |

Table 6. Control of Septoria leaf blight and glume blotch in winter wheat with foliar applications of Tilt - G. Schnappinger (MD).

| Treatment | Rate (g ai/A) | Schedule | Septoria leaf blight | Glume blotch | Yield (bu/A)[a] |
|---|---|---|---|---|---|
| Tilt | 50 | 8 + 10.1 | 4.1 | 9.0 | 68.0a |
| Check | -- | -- | 66.8 | 28.0 | 53.8b |

[a] Yields with different letters are significantly different at the P = 0.05 level.

Table 7. Control of leaf rust in wheat with foliar applications of Tilt. - L. Anzalone (Louisiana State University).

| | | Arthur 71[1] | | McNace 1003 | | Southern Belle | | Coker 6815 | |
|---|---|---|---|---|---|---|---|---|---|
| Treatment | Rate (g ai/A) | Rust | Yield (bu/A)[a] | Rust | Yield (bu/A) | Rust | Yield (bu/A) | Rust | Yield (bu/A) |
| Tilt | 50 | 3.1 | 49.6a | 12.8 | 51.3a | 3.0 | 56.3a | 0.6 | 62.0 |
| Check | -- | 80.0 | 30.3b | 98.8 | 28.7b | 13.3 | 41.9b | 6.5 | 37.1 |

[a] Yields with different letters are significantly different at the P = 0.05 level.

Table 8. Control of stripe rust on 'Orin' wheat with foliar applications of Tilt. - R. Powelson (Oregon State University).

| Treatment | Rate (g ai/A) | Schedule | Disease rating | Yield (metric tons/A)[a] |
|---|---|---|---|---|
| Tilt | 50 | 7 + 9 | 0.04 | 4.0a |
| Check | -- | -- | 40.0 | 3.17b |

[a] Yields with different letters are significantly different at the P = 0.05 level.

In conclusion, although more intensive management of wheat is practiced in Europe, many areas of the United States with high production potential, yield loss due to disease may be comparable on percentage basis. Due to higher yields and market prices, economic thresholds for wheat disease in Europe may be lower than in the United States. A challenge in the United States is to define more precisely the economic thresholds of various cereal diseases and the expected economic return from fungicide applications. A more thorough economic analysis of intensive wheat production is needed in order to determine how to maximize return per unit of production. In recent results obtained by Dr. Jim Kantzes and Dr. David Sammons (University of Maryland) increased nitrogen fertilization and foliar fungicide applications significantly increased wheat yields (Table 9).

Table 9. Effect of increased nitrogen fertilization and foliar fungicides on wheat yield - J. Kantzes and D. Sammons (University of Maryland).

| | Yield (bu/A) | | | |
|---|---|---|---|---|
| | Fertilizer/A (lb nitrogen/A) | | Fertilizer + fungicide[a] | |
| Variety | 60 | 120[b] | 60 | 120 |
| Tyler | 82.3 | 98.1 | 85.7 | 119 |
| Blue Boy | 60 | 69.6 | 76 | 89 |

[a] Two applications of Bayleton + Difolatan were made.

[b] Split applications of nitrogen (60 lb/A) were applied while the wheat was dormant in February and again at 12-inch growth.

The variety Tyler yielded 82.3 bu/A with 60 lb of nitrogen and no fungicide treatments. When nitrogen rates were increased to 120 pounds per acre and two Bayleton + Difolatan treatments were applied, yields increased to 119 bu. In the variety Blue Boy, yields were 60 bu/A in the 60 lb of nitrogen treatment, while plots which received 120 lb of nitrogen per acre and two Bayleton + Difolatan treatments, yielded 89 bu/A. Powdery mildew was the major disease present during the study. Bayleton is another sterol-inhibiting fungicide similar to Tilt.

As these data indicate, maximum benefits from foliar fungicide applications are obtained when fungicide applications are used in combination with improved varieties and cultural practices. Maximum potential returns for fungicides lie in those areas where sufficient moisture is available and more intensive production practices are utilized, such as in the Pacific Northwest, Northeast, Southeast, Gulf Coast States and parts of the Midwest. Experimental data obtained from these areas indicate that in the presence of disease, yield increases comparable to those observed in Europe (on a percentage basis) are often obtained when Tilt is applied to cereals.

# WEEDS IN WHEAT PRODUCTION

John D. Nalewaja
Department of Agronomy,
North Dakota State University,
Fargo, North Dakota

Wheat was seeded to 87 million acres of U.S. cropland in 1982. Wheat occupied more area than any other U.S. crop and also occupies more area than any other crop worldwide. The immense area dedicated to production of wheat indicates its tremendous importance to the sustenance of mankind and also indicates the importance of effective economical weed control. Weeds in wheat reduce yields and weed control by whatever means is a tremendously important task. For example, the worldwide loss in wheat and barley production in 1977 from wild oats alone was estimated at 13 million metric tons/year or enough calories to feed 50 million people for one year.

Tremendous progress has been made in the control of weeds in wheat over the past 30 years. Today most major annual broadleaf weeds are controlled adequately by herbicides. However, specific resistant annual species of minor importance exist in localized areas and may become major problems in the future. False chamomile in North Dakota is an example. Perennial weeds are still important problems in wheat production. Grass weed control has improved with recent development of herbicides and management systems for wild oats, green and yellow foxtail, and ryegrass; however, present control practices are inadequate for cheat, downy brome, and jointed goatgrass.

Weeds in wheat continue to infest and cause wheat yield losses even with presently available control systems. A preharvest survey which sampled 5 square meters for weeds in wheat fields of Minnesota, North Dakota, and South Dakota in 1979 indicated that certain weeds still occurred frequently, as indicated in Table 1.

The field frequency values presented in Table 1 generally reflected the weed index which was developed based upon weed frequency, uniformity, and density for comparative purposes. However, the index indicated that foxtail was more important in wheat in South Dakota than in North Dakota or Minnesota even though the frequencies were similar in North Dakota and South Dakota. Green and yellow foxtail were considered together in South Dakota with an index of 520 and separately in North Dakota with a combined index of 315. The total number of weed species to infest wheat was 57 in Minnesota, 63 in North Dakota, and 53 in South Dakota.

Weed infestations vary from year to year and changes may have occurred since 1979, but the results of the above survey indicate that weeds are important in wheat fields even with control practices. In 1978, 8.6 million acres or 80% of the North Dakota wheat was treated with a herbicide. Herbicide usage was probably similar in 1979, the year of the weed survey.

Table 1. Weeds with more than a 30 percent occurrence frequency in Minnesota, North Dakota, or South Dakota wheat fields, 1979.

| Species | Percent frequency | | |
|---|---|---|---|
| | ND | MN | SD |
| Green foxtail | 95(279)[a] | 63(121)[a] | 96(520)[a] |
| Wild oats | 67 | 59 | 34 |
| Wild buckwheat | 66 | 60 | 54 |
| Pigweed sp. | 67 | 38 | 39 |
| Yellow foxtail | 27 | 46 | -- |
| Common lambsquarters | 40 | 31 | 35 |
| Wild mustard | 39 | 39 | 7 |
| Russian thistle | 33 | 4 | 43 |
| Kochia | 27 | 6 | 49 |
| Canada thistle | 17 | 36 | 7 |
| Field bindweed | 19 | 1 | 34 |
| Smartweed | 1 | 36 | 1 |

[a]( ) = weed index values which involve weed density, field occurrence, and uniformity.

The wheat yield loss from seven weeds was more than 44 million bushels for North Dakota alone, an estimate based upon the 1979 infestation and weed competition data, as presented in Table 2. The yield losses may have decreased since 1979 with the development of wild oats control management systems and registration of diclofop (Hoelon). In addition to yield losses, the weeds caused an expense for herbicides and herbicide application, tillage for weed control, and reduced yield from delayed seeding for weed control. The survey in 1979 indicated that 59% of the North Dakota wheat producers practice delayed seeding for wild oats control. Delayed seeding for wild oats control requires one to two more tillages than early seeding and often causes yield reductions which exceed 30%.

New herbicides have caused some concerns relative to the economic returns from usage because of their high cost. The results of an experiment to assess the benefits from weed control in wheat was conducted in North Dakota and the results are presented in Table 3.

Weeds are often severe competitors with wheat causing large yield reduction. The wheat which was not given any weed control only yielded 8.9 bu/A, averaged over two years (Table 3). The yield was increased 5.6 to 24.6 bu/A by various weed control methods. The triallate-bromoxynil-diclofop herbicide treatment cost about $30/A with a $18.90 net return. Hand hoeing was included for reference, but the hoeing cost was $744/A with lower yields than the herbicide treatment for a net loss to the hoeing practice of $727.20/A. Thus, when competitive weeds are present in wheat, relatively high expenditures for herbicides provide a favorable return.

The data in Table 3 are averages over two years and in one year the increased return from adding diclofop to the triallate bromoxynil treatment was $11/A and in the other year only $1/A. In the year where the return was $11/A the earlier triallate treatment had not adequately controlled the wild oats while in the year with the $1/A net return to diclofop the triallate gave good wild oat control. The question which needs to be answered is whether the reduced weed seed production from control of populations below economic return levels warrants control to reduce inputs in subsequent years? Another important related question is, what is the density for various weeds in a given environment for an economic return in the year of treatment. Base data are needed on weed population dynamics and the influence of environment on weed crop interactions to help answer the above questions for profitable management decisions.

Table 2. Yield losses from selected weeds in wheat, North Dakota 1979.

| Species | Weeds in wheat: Frequency | Density | Acres | Wheat: yield | loss |
|---|---|---|---|---|---|
| | (%) | ($Pl/m^2$) | (1000) | (%) | (1000 bu) |
| Green foxtail | 95 | 75 | 9,405 | 5.0 | 13,018 |
| Yellow foxtail | 27 | 21 | 2,673 | 1.5 | 1,070 |
| Wild oats | 67 | 8 | 6,633 | 7.0 | 13,130 |
| Wild buckwheat | 66 | 4 | 6,534 | 1.0 | 1,735 |
| Wild mustard | 39 | 3 | 3,861 | 2.4 | 2,497 |
| Field bindweed | 19 | 5 | 1,881 | 9.0 | 4,893 |
| Canada thistle | 17 | 2 | 1,683 | 15.0 | 7,811 |
| | | | | | 44,154 |

Table 3. The returns from the control of wild oats and other weeds with various practices in wheat, Fargo, North Dakota 1978 and 1982.

| Weed control treatment | Wheat yield: Total | Gain | Total[a] return | Weed control[a]: Cost | Return |
|---|---|---|---|---|---|
| | ----(bu/A)--- | | ----------($)---------- | | |
| None | 8.9 | -- | 26.3 | 0 | ---- |
| Hoeing (222h) | 19.5 | 5.6 | 43.5 | 744 | -727.2 |
| Triallate+bromoxynil | 21.2 | 12.3 | 63.6 | 18 | 18.9 |
| Triallate+bromoxynil+diclofop | 26.1 | 17.2 | 78.3 | 30 | 21.6 |
| Triallate+bromoxynil+diclofop+ hoeing (74 h) | 33.5 | 24.6 | 100.5 | 280 | -206.2 |

[a]Wheat at $3.00/bu, hoeing at $3.35/h, and other treatment costs were herbicide plus application plus incorporation.

The first important step towards reducing losses from weeds in wheat has been accomplished through the development of herbicides for the control

of many important weeds in wheat. Some management systems have been developed to improve control beyond herbicides alone. Many weed species remain, however, which are not adequately controlled with present control measures, and new weeds will infest wheat grown without tillage. Canadian thistle, quackgrass, milkweed, field bindweed, nightflowering catchfly, false chamomile, sowthistle, cheat, and jointed goatgrass are some of the weeds which are not adequately controlled in wheat.

The second step needed in weed control is to reduce the cost for control. The use of herbicides gives returns beyond the cost for control. However, the cost for the herbicides or other control practices needs to be reduced because weed control adds important costs to wheat production. The reduction in the cost for weed control through techniques which reduce herbicide and tillage will require intensive research on the basic aspects on herbicides, weeds, crops, and their interactions in various cropping systems. This research will require support from the public sector because of the lack of a profit incentive for an industrial concern to make the investment.

In summary, weeds in wheat are causing large losses in wheat productivity and profitability. These losses warrant greater investments by the public in research to reduce these losses or at least to determine the feasibility of further reducing losses from weeds below those with present control practices.

# DEVELOPMENT OF AN INTEGRATED PEST MANAGEMENT PROGRAM FOR WHEAT IN THE SEMIARID REGIONS OF THE WESTERN UNITED STATES

G. A. McIntyre
Colorado State University
Fort Collins, Colorado

## Need for An Integrated Pest Management Program

Traditionally, control of pests on crops was based on a firm foundation of biological principles that predicted the interaction between host and pest in the agroecosystem. After World War II, however, development of organic pesticides (for example, 2,4-D and DDT) caused a marked shift in the philosophy of pest control. The broad foundation of control based on biological principles was essentially abandoned for a pesticide-oriented system in which a specific pest or group of pests was controlled by a pesticide with little regard to the total impact on the agroecosystem. Increased reliance on pesticides for control has produced a substantial change in the varieties of individual crops developed and how they are grown. Current crop varieties were developed to respond to greater usage of pesticides, more fertilizer, and increased irrigation (3). This has led to an increasingly homogeneous cropping system in which the crop has a narrower gene pool and is more susceptible to attack from pests (corn to southern corn leaf blight) (2,5). This genetic vulnerability has, in turn, created higher demand for use of more pesticides at higher concentrations and greater frequency. This practice has reduced the number of natural predators and parasites of pests normally found in the cropping system thus allowing, in some instances, rather minor pests to assume a new, major importance. More recently, evidence has been gathered (4) which shows that pesticide-resistant races of pests have developed in response to the intensive use of certain pesticides. Both reduction in natural enemies of pests and development of resistance of pests to pesticides have created a situation whereby either new methods of control must be developed or still more pesticides used. As the latter is neither cost effective nor environmentally safe, it is clear that new, economically sound means of controlling pests must be developed. This calls for the integration of control procedures into a management system based on the understanding that pest species are single components of a complex agroecosystem and that the interaction of these components transcends the artificial barriers created by the traditional, taxonomically oriented crop protection disciplines (1). Although such a system may require utilization of pesticides, use is incorporated into an overall system that will ensure that pesticides are applied strategically in minimum quantities to assure control with minimal adverse effects upon the environment.

Development of such systems is referred to as Integrated Pest Management (IPM). IPM, as it is often conceptualized, deals with one pest or complex of similar pests (boll weevil-cotton or boll weevil and bollworm complex-cotton) on a single crop. Although this approach has provided significant progress toward control of pests in these rather narrowly defined systems, it does not address the impact of these control measures on an entire agroecosystem. Clearly, to establish an IPM program for an entire agroecosystem, interactions

such as those between pests, pests and parasites, pests and predators, or pests and hosts and the effect of cultural practices, soils, irrigation practices, microclimate, and surrounding fauna and flora in a specific geographical area must be considered. To develop a scheme that recognizes the large number of interactions occurring within the system, calls for an interdisciplinary effort incorporating not only traditional crop protection disciplines, but also disciplines not ordinarily involved in agricultural sciences such as systems analysis, microclimatology, and hydrology. This multidisciplinary effort must provide current information on pests to be controlled, their natural enemies, crop phenology, weather, etc., and the interaction of each of these with the others. The ultimate measure of success of such a program will be the ability of the IPM research component to provide to the extension component a cost-effective, environmentally safe program that will be acceptable to the farmer.

Potential for a Wheat IPM Program in the Western Region:

The western region of the United States can be divided into four major agroecosystems. These are:

(A) Semiarid irrigated: once desert or semidesert lands, economically the largest agronomic production base.

(B) Semiarid dryland: wheat-fallow and most of the western range; geographically the largest unit.

(C) Subhumid - winter rainfall: annual crops and orchards.

(D) Subhumid - summer rainfall: annual crops.

Of the four agroecosystems mentioned above, A and B are common to all of the Western States, include most of the land in the western region, are essentially unique to the region, and are the most important economically.

The semiarid, irrigated agroecosystem includes over 12 million acres and produces an annual cash income of 3.7 billion dollars to the farmers of the region. The semiarid, dryland system includes over 19.8 million acres in small grain production and over 368 million acres classified as range. The annual cash income for small grains exceeds 2.3 billion dollars (6, 7).

Undisturbed soils within these regions are low in organic matter and have a simple, fragile biological community in comparison with the rich flora and fauna associated with soils of eastern forests and prairies. The increased complexity of the biological community of eastern soils is far more stable than that found in western soils. Cultivation and irrigation of these soils containing unstable biological complexes creates a dramatic shift in species found within the community and creates previously unavailable niches (Fig. 1). These niches are colonized rapidly by introduced organisms that are often serious pests to wheat and other crops. The high initial yields associated with crops grown on lands recently brought under cultivation for the first time, drop rapidly as the soil environment is colonized by introduced pests. For example, high yields of potatoes can only be maintained through the rigorous application of soil fumigants, a pesticide use in which the West leads the United States. Terms such as "spudded out" and "potato decline" are used by growers to describe

"Simple" biological community

in balance with the dry climate

↓

Land cleared, filled, and irrigated

New biological niches created;

Existing biological community poorly adapted to new environment

and inadequate to buffer against new organisms

↓

Introduced pests are best adapted

and flourish--yields decline

Tolerate losses

Good crop rotation

Pest problems maintained in continual state of flux; natural enemies of pests increase slowly, but pest populations also maintained at lower and more tolerable level.

Monoculture

Pests of single crop favored, but so are natural enemies so pest populations eventually decline. A new balance different from that found in crop rotation is created.

Move to new land

Fumigate

Pests temporarily controlled, but natural enemies of pests also eliminated so fumigation becomes continuous component of cropping practice.

Fig. 1. Arid or Semiarid Lands

the ever growing problem of dramatic yield loss associated with the spectacular increase in pests on these lands. Growers are confronted with either fumigating, a control system which is expensive to maintain production, abandoning the land and moving to a new area where the previously described cycle is repeated, or accepting yield losses that often make farming economically unfeasible (Fig. 1).

The arid climate of the Western States greatly limits airborne pathogens and insect pests. This has placed much of the West in a favored position regarding production of disease-free seed for other regions of the United States where summer rainfall and high humidity provide an optimum environment for development of numerous leaf spots, blights, fruit rots, insects, and weeds, despite the rigorous application of pesticides. However, this advantage is rapidly being lost in the West. The advent of the modern, center pivot sprinkler irrigation system which can deliver overhead moisture to every plant in a field as frequently as every 6-12 hours has created a local environment that has the high humidity associated with the eastern agrocecosystems. Consequently foliar pests are rapidly becoming major problems to crops grown under irrigation.

Usually, soilborne pathogens are immobile and thus remain confined to fields. Unfortunately where irrigation canals are used, soilborne plant pathogens, and weed seeds in particular, may become widely distributed from field to field and throughout the irrigation districts by one of the most efficient means of dissemination ever designed. Quarantines become academic in this situation. One grower's problem is transformed in a single season to every grower's problem.

For dryland agriculture, and more specifically dryland wheat, water stress and associated soilborne disease problems are more evident in the Western States than in any other wheat growing area of the United States. Unlike the Great Plains States, dryland wheat in the Western States is grown on stored summer fallow moisture with no effective rainfall after April or early May.

Substantial numbers of scientists in the West in Experiment Stations, ARS, and Extension are already deeply involved in activities related to the management of the semiarid dryland and semiarid irrigated agroecosystems. It is with appreciation for the economic and geographic importance of these systems to the West and the commodity linkages that tie the two together that a regional IPM program was initiated.

<u>Project Objectives</u>

In August 9-11, 1978, the Experiment Station directors of the Western Region authorized the initiation of a regional coordinating Committee to "consider the various alternatives for organizing an Integrated Pest Management project in the Western Region, prepare a regional research project outline based on the chosen organizational method, and investigate various methods of funding the project."

As part of the activities of this committee, two major agroecosystems in the western region and the crops, including range, grown upon them have been

identified as the most important for development of a coordinated, regional effort in integrated pest management. The objectives of the project are:

1. To assess impact of pests and plant protection by:

    a. Individual commodities

    b. Crop production systems

2. To identify and prioritize pest complexes amenable to IPM

3. To develop, refine, and implement IPM systems for selected pest complexes by:

    a. Obtaining or refining additional biological, climatological, agronomic, and economic data and initiating systems analysis, modeling and simulation technologies for individual commodities

    b. Developing and implementing new IPM systems

## Project Organization

### Commodity Coordinating (CC) Subcommittees

The Western Regional IPM Project offers a significant departure from the more traditional means of supervising regional projects of multidisciplinary, multicommodity IPM research programs and requires a substantial cooperative effort by administrative units in ARS, Extension, Experiment Stations, Resident Instruction (RI), and Agribusiness. There is no one administrative structure within the region that satisfies this closely coordinated effort. Consequently, a new, innovative approach has been developed. While the two agroecosystems and commodities grown in each will provide the confines in which the project operates, we have chosen to place far greater emphasis on the pest complexes associated with the cropping systems in the Western Region rather than the crops *per se*. Our emphasis is on controlling pest complexes that are impacted by the entire management system within a rotation.

The objectives of the project are being met through the creation of a series of multiagency, multidisciplinary Commodity Coordinating (CC) committees that have identified high priority pest problems for wheat and other commodities and have recommended those pest complexes which should receive highest priority for research support. Several pest complexes of small grains appear amenable to an IPM approach. The Small Grains CC Committee has identified two, with the anticipation that others will be added in the future. The two, in order of priority are: barley yellow dwarf (BYD) and wild oats. Both of these pest complexes are too difficult to be solved by any one discipline, state, or agency. A regional cooperative system to implement IPM for barley yellow dwarf and wild oats will require formation of subcommittees to address these pest complexes specifically. Fig. 2 illustrates the structure envisioned for the BYD subcommittee and its relationship to the CC Committee. The wild oat subcommittee would be structured similarly with the disciplines drawn from areas most related to solving this problem.

Although the procedures outlined use BYD as an example, the total IPM effort for small grains will be expanded to other pest complexes as soon as resources and available data permit. Other pest complexes that will be evaluated and considered for IPM are: wire worms, leaf rust, downy brome (cheatgrass), and Hessian fly. These are all major pest problems in the semiarid wheat fallow regions, annual cropped regions, or both; and current effort aimed at their control is minimal or nonexistent.

## Future Plans

The Small Grains CC Committee plans to continue its efforts in the assessment of the status of pests and plant protection for western small grains. An additional goal is, through systems analysis, to describe as completely as possible, the "state of the art" for pest control in small grains in a document that could serve as a manual for research, extension and teaching.

## Summary

The Western Region has made significant progress in developing an IPM system which addresses the problems associated with control of pest complexes such as barley yellow dwarf on wheat. The proposed model maximizes opportunities for interdisciplinary, interagency cooperation and provides a realistic means for establishing regional research priorities for control of this pest complex. It is anticipated that additional pest complex problems such as wild oat infestations will be incorporated into the project as time and resources become available.

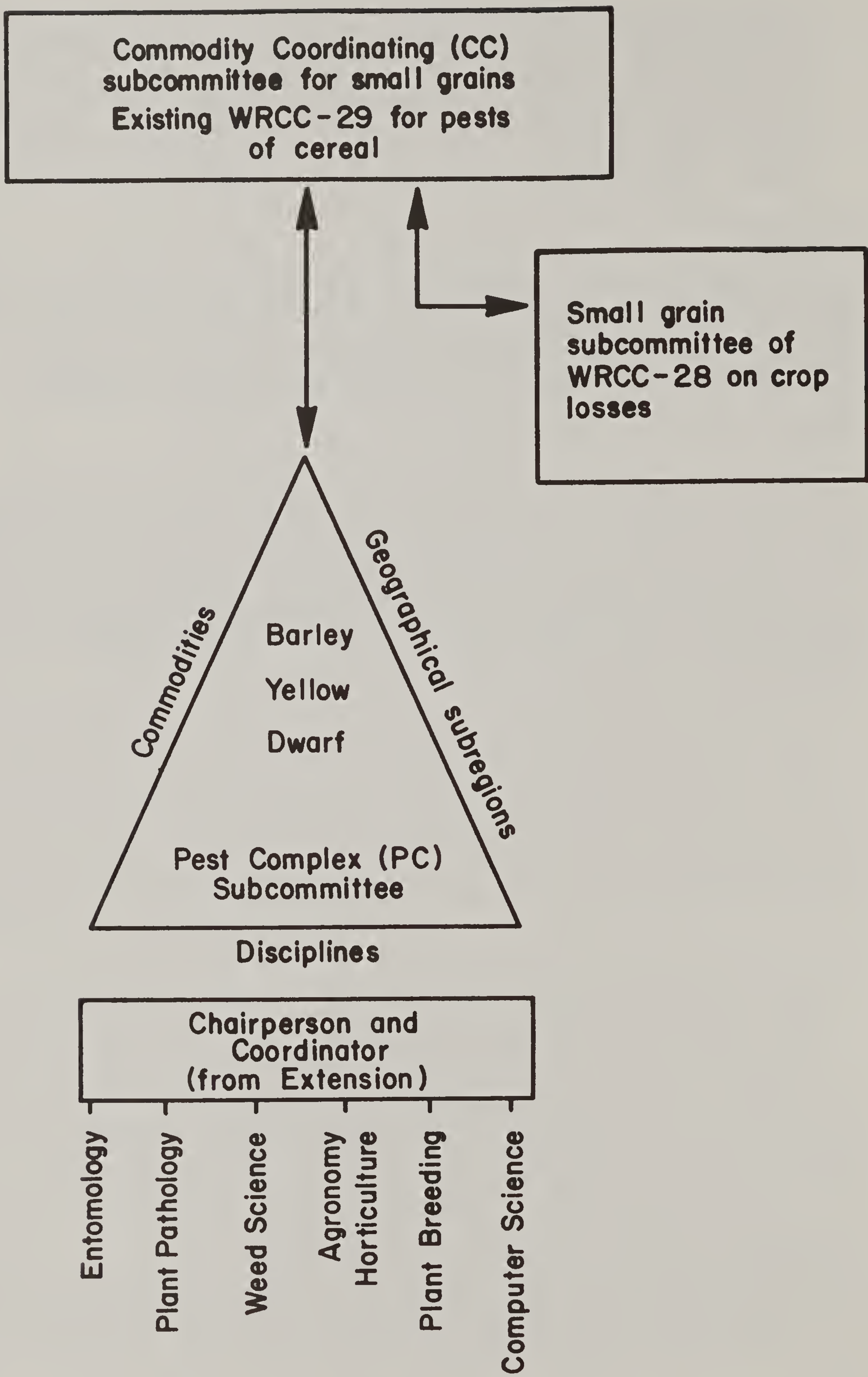
Commodity Coordinating (CC) subcommittee for small grains
Existing WRCC-29 for pests of cereal
Small grain subcommittee of WRCC-28 on crop losses
Commodities
Geographical subregions
Barley
Yellow
Dwarf
Pest Complex (PC) Subcommittee
Disciplines
Chairperson and Coordinator (from Extension)
Entomology
Plant Pathology
Weed Science
Agronomy
Horticulture
Plant Breeding
Computer Science

Fig. 2

## References


1. Glass, E. H. 1976. Pest management: Principles and philosophy, p. 39-50: In: I. L. Apple and R. F. Smith (eds.) Integrated pest management. Plenum Press, New York.

2. National Academy of Sciences. 1972. Genetic vulnerability of major crops. Committee on Genetic Vulnerability of Major Crops. Washington, D. C. 307 pp.

3. National Academy of Sciences. 1975a. Agricultural production efficiency. Washington, D. C.

4. National Academy of Sciences. 1975b. Pest control: An assessment of present and alternative technologies. Vol. 1. Contemporary pest Control Practices and Concepts. Washington, D. C.

5. Smith, R. F., J. L. Apple, and D. G. Bottrell. 1976. The origins of integrated pest management concepts for agricultural crops, p. 1-16. In: J. L. Apple and R. F. Smith (eds.) Integrated pest management. Plenum Press, New York.

6. United States Department of Agriculture. 1979. Crop values (1976-1977 -1978)--season and average prices received by farmers and value of production. CR. Pr 2-1(79). 29 pp.

7. United States Department of Agriculture. 1979. Crop production, 1978 annual summary--Acreage, yield, production. CR. Pr 2-1(79). 42 pp.

# ROLE OF PLANT GROWTH REGULATORS IN SMALL GRAIN PRODUCTION

T.S. Smith
Union Carbide Agricultural Products Company, Inc.
Portage, Michigan

## Abstract

Ethephon [(2-chloroethyl)phosphonic acid], a plant growth regulator, has been evaluated for controlling lodging in barley and wheat in over one hundred and twenty-five trials in North America since 1980. Ethephon reduces lodging in barley and wheat which is caused by excessive fertility or abnormal weather. Rates of 0.25 to 0.5 lb/a applied between the stages when the flag leaf is first visible and late boot stage effectively reduce stem elongation, increase straw strength, and reduce lodging. Barley is more responsive to ethephon treatments than wheat, with distinct class and varietal differences in wheat. Ethephon registration under the trade name CERONE, is expected for barley and wheat in time for the 1983 use season.

## Introduction

Plant growth regulators are currently used widely by European grain producers to control lodging in cereal crops. This practice has allowed growers to increase fertility and other inputs to maximize the yield potentials of the varieties grown. Additionally, European plant breeders have specifically developed high yielding varieties designed to be grown in cultural regimes which include the use of plant growth regulators (for lodging control) along with fungicides and insecticides. This integrated approach to grain production, combined with excellent growing conditions, produces grain yields about twice the U.S. average. In Western Europe, over fifty percent of wheat and over fifteen percent of barley are treated with plant growth regulators for antilodging. Effective antilodging agents for barley have only recently become available. Three plant growth regulators are currently being marketed for this use: chlormequat chloride [(chloroethyl)trimethylammonium chloride], ethephon [(2-chloroethyl)phosphonic acid], and a combination of ethephon and mepiquat chloride (1,1 dimethylpiperidinium chloride).

Chlormequat chloride has been marketed under the trade name Cycocel since the late 1960's. It was the first plant growth regulator registered for antilodging in wheat. Chlormequat chloride is applied at stem elongation, growth stages 5.0 to 6.0 on Feekes-Large scale. This treatment produces thicker and shorter stems resulting in a sturdier and more compact plant. Barley is less responsive to chlormequat chloride, thus it has not been registered for use on barley. In response to a critical need for an antilodging material in barley, ethephon was developed and registered under the trade name CERONE in the late 1970's. Ethephon is applied to barley from the time the flag leaf is first visible to the time the first spikelet is visible, growth stages 8.0 to 10.1 on Feekes-Large scale. Ethephon also produces a thicker and shorter stem, and the result is a sturdier and more compact plant. Ethephon is used primarily on barley but registrations for this use on wheat throughout Western Europe is expected for the 1983 use season. Timing of application and plant responses for wheat are the same as for barley. The third product, a combination of mepiquat chloride and ethephon has been developed recently for

barley and is marketed under the trade name Terpal. It is applied from the time the first node is visible until the flag leaf appears, growth stages 6.0 to 8.0 on Feekes-Large scale.

There are some major differences between European and North American cultural practices for small grain production. Most small grain cereal fields in Western Europe are seeded to contain tram lines, which are blank rows wide enough to accomodate the tire tracks of ground equipment. These tram lines greatly facilitate ground application of plant regulators or pesticides any time during the growth cycle of the crop. Leaving the blank rows for tram lines will decrease the plant population but will not affect grain yields. Another major difference in European cultural practices is the row spacing. A four-inch row spacing, instead of a seven-inch or a ten-inch row spacing, is used in Europe. A four-inch row spacing generally results in ten to fifteen percent yield increases over the conventional seven-inch row spacing.

Small grain production practices in North America have remained relatively unchanged for more than a decade. Major emphasis has been placed on the development of new varieties with disease, insect, and lodging resistance. An excellent job has been done. However, there is growing evidence of American grower dissatisfaction with current yield levels. European success stories, high interest rates, and low commodity prices have all contributed to greatly increased grower interest in increasing yields as a means of reducing unit production costs. A number of growers approached Union Carbide Agricultural Products Company, Inc. in the winter of 1980 expressing an interest in CERONE Plant Regulator, a material widely used in Europe for antilodging in small grain cereals. These growers were greatly interested in maximizing yields, but had reached a point in their fertility program where lodging had become a significant problem. Discussions with these growers resulted in the initiation of a research program by Union Carbide, and over 125 trials have been conducted to date. This work was conducted under a Canadian Research Permit in 1981 and 1982. CERONE registration is expected in both countries in time for the 1983 season. The remainder of this paper will report the results of a few of the research trials and discuss the advantages and limitations of ethephon use on small grain cereals. Chlormequat chloride and mepiquat chloride are not under intensive development on small grain cereals in this country; therefore, they will not be discussed here.

## Materials and Methods

Ethephon was applied in grower and small plot field trials by air, ground, or small plot sprayers. Spray volumes ranged from three to forty gallons per acre. Ethephon rates ranged from 0.25 to 0.5 lb per acre and were applied between growth stages 8.0 and 10.0 on the Feekes-Large scale. These stages correspond to the flag leaf first visible and the swollen boot stage of growth.

Among the parameters measured were plant height, kernel weight, yield, and degree of lodging. The following lodging rating system, adapted from Belgium, was utilized:

$$\text{Lodging index} = S \times I \times 0.2$$

where:

S = area of surface lodged
(1 = no lodging, 9 = total lodging)

I = intensity of lodging
(1 = completely upright, 5 = completely flat)

The factor of 0.2 is used to bring the final figure into the scale of 0.2 to 9.0 (linear); 0.2 = no lodging, 9.0 = total area flat.

Results from the following trials will be presented:

a. Winter wheat: Newton variety was seeded on a silt loam soil near Arkansas, City, Kansas on October 1, 1980. Sixty pounds of nitrogen was applied in the fall and twenty additional pounds in the spring. Treatments were arranged in a randomized complete block design with four replications in 15 x 25-foot plots. Ethephon at 0.25 and 0.5 lb/A was applied at growth stage 10.0 in twelve gallons of water per acre with a small plot sprayer. Replicated square yard samples were hand harvested for yield. Growth measurements at harvest are reported in Table 1a.

b. Spring wheat: Butte and Era varieties were seeded in a clay loam field near Appleton, Minnesota on April 19, 1982. Normal fertility (80 lbs N per acre) practices were followed for Butte, whereas Era received 40 lb of additional N per acre than normal. Ethephon at 0.25 lb/A was applied between growth stages 8.0 and 9.0 with a pickup-mounted sprayer. This treatment consisted of an unreplicated 4.5-acre plot. Both treated and untreated areas received two applications of nabam(Dithane) and one of malathion. These fields were under a center pivot irrigation system. Only lodging, height, and yield measurements were obtained from this trial as reported in Table 1b.

c. Spring barley: Moravian III variety was seeded in a loam soil near Longmont, Colorado on March 20, 1981. All plots received fifty pounds additional nitrogen at planting. The treatments were arranged in a randomized block design with four replications in 7.5 x 25-foot plots. Ethephon at 0.25 and 0.5 lb/A was applied at growth stage 10.0 in twenty-three gallons of water per acre with a small plot sprayer. Replicated 120-square-foot samples were taken for yield. Growth measurements at harvest are reported in Table 1c.

## Results and Discussion

The results from the trials outlined above are presented in Table 1. The data are discussed in a general way to include the information gathered over the last three years.

Table 1. Effect of Ethephon on Lodging, Height, and Yield of Small Grain Cereal Crops.

a. Winter Wheat (Newton) - Arkansas City, Kansas- 1981

| Ethephon (lb./A) | G.S.* At Applic. | Plant Height (Inches) | Lodging Index** (0.2-9.0) | 1000 Kernel wt. (g) | Yield (bu/A) |
|---|---|---|---|---|---|
| Check | -- | 33.9 | 4.5 | 31.7 | 66.5 |
| 0.25 | 10.0 | 29.9 | 0.3 | 34.2 | 74.1 |
| 0.50 | 10.0 | 29.3 | 0.2 | 33.5 | 64.5 |

b. Spring Wheat (Butte and Era) - Appleton, MN- 1982

| Ethephon (lb./A) | G.S.* At Applic. | Plant Height (Inches) | Lodging Index** (0.2-9.0) | Yield (bu/A) |
|---|---|---|---|---|
| Butte | | | | |
| Check | -- | 31.5 | 8.0 | 40.0 |
| 0.25 | 8.0-9.0 | 35.4 | 2.8 | 86.1 |
| Era | | | | |
| Check | -- | 34.7 | 9.0 | 55.0 |
| 0.25 | 8.0-9.0 | 33.6 | 2.8 | 69.1 |
| 0.50 | 8.0-9.0 | 32.0 | 0.2 | 74.4 |

c. Spring Barley (Moravian III)- Longmont, CO- 1981

| Ethephon (lb./A) | G.S.* At Applic. | Lodging Index** (0.2-9.0) | 1000 Kernel Wt. (g) | Yield (bu/A) |
|---|---|---|---|---|
| Check | -- | 3.3 | 36.3 | 75.8 |
| 0.25 | 10.0 | 0.2 | 37.2 | 99.5 |
| 0.50 | 10.0 | 0.2 | 37.7 | 94.4 |

* Growth stages on Feekes-Large scale
** Belgian system: 0.2 = no lodging, 9.0 = total area flat

Ethephon, between 0.25 and 0.50 lb per acre, effectively controlled lodging in small grain cereals. In wheat and barley, the timing of application is between the time the flag leaf first appears and the boot is swollen. This timing is from growth stages 8.0 and 10.0 on the Feekes-Large scale. It is very important to make ethephon application only at those growth stages to obtain optimum antilodging response. Ethephon inhibits the elongation of the last two internodes of the plant so it is shorter than normal. Ethephon also increases straw strength by increasing cellulose and lignin content of the straw. The shorter, stronger plant resist lodging which is caused by excessive fertilization or unfavorable weather conditions.

Barley is much more responsive to ethephon than winter or spring wheat. Rates of 0.25 lb ethephon/A will dramatically retard barley growth more than wheat. However, increasing straw strength may be as important as shorter plants in lodging control. Generally 0.38 lb ethephon/A is required to control lodging in winter and spring wheat. A significant amount of work remains to be done in identifying varieties which will respond to increased fertility and those that benefit from a plant growth regulator application. Tall and intermediate varieties, which have been discarded by growers due to lodging problems, appear to offer the greatest potential. Lodging control in these types has resulted in up to forty bushel per acre yield increases. Many of these increases have been obtained without additional fertilization. With semi-dwarf varieties, excellent lodging control has been obtained, but yields have not been significantly improved. Ethephon may adversely affect head fill in these lines. Growers will be cautioned not to use ethephon on these varieties until research is completed.

Grower trials have been conducted by using both normal fertilization practices, as well as additional nitrogen. Results have shown that additional nitrogen does not always increase yields or cause lodging. Disease and rainfall then become limiting factors. Additional nitrogen may not pay for itself by additional yields, and the lush growth can be more susceptible to diseases. Selection of disease resistant varieties or use of fungicides combined with irrigation may provide the highest return on their investment.

Interesting results are being obtained from wheat and barley trials with ethephon when no lodging occurs in the check areas. Significant yield increases of up to ten bushels per acre are being obtained in the absence of lodging. Yield components are being analyzed to help understand this phenomenon.

Some of the benefits reported by growers who evaluated ethephon in 1981 are as follows:

1. A standing crop minimizes harvesting losses.

2. Harvesting efficiency was improved. In many fields it took 1 1/2 to 2 times longer to harvest the lodged crop than the standing crop.

3. Grain quality was improved by reducing molding and sprouting. Where swathing is practiced, growers were able to cut higher and leave the grain on a bed of straw stubble.

4. Depending on the time when lodging occurred and the normal harvest time, yield increases were realized by lodging control. The earlier the crop lodges, the greater the possibility for yield loss, if lodging is not controlled.

5. Effectiveness of treatment could eliminate the need for swathing grain. Direct combining is a distinct possibility.

6. Yield increases were obtained with ethephon application made to areas receiving normal fertility, in the absence of lodging, particularly tall straw varieties.

7. "Necking" of small grain was significantly reduced. Head loss before harvest was minimized.

Growers and researchers should note the following limitations:

1. The proper application timing is critical. Small grain can go from growth stage 8.0 to 10.0 in a matter of five to ten days, depending on weather conditions. A week of wet weather could prevent timely application of ethephon.

2. The stage of growth for ethephon application necessitates the use of an aerial applicator or running over the grain with ground equipment. Wide swathing by aerial applicators resulting in poor coverage is a serious problem and is readily apparent when using a plant growth regulator. For growers not hesitant to drive over the crop, the height of the spray boom became a problem.

3. Plant growth regulators do not prevent lodging caused by disease. Additional fertility can increase disease problems. Ethephon is tank mixed and applied with commercially available fungicides in Europe. Research of this type is presently being conducted in the United States.

4. Leaf rust appears to be enhanced, in several trials, where rust susceptible varieties were treated with ethephon. Rust was present before application. This interaction will be evaluated extensively in 1983.

The use of plant growth regulators in small grain production provides an opportunity for new varieties to be released and old varieties to be rediscovered. With lodging control, new yield plateaus can be reached. The plant growth regulators used on small grain cereals in Europe are the result of American technology. It now appears that the time is right for this technology to be utilized in the United States and Canada.

# HYBREX(TM)[1] TECHNOLOGY

Charles H. Baker
Seed Business Operations Manager,
Rohm and Haas Company,
Independence Mall West,
Philadelphia, Pennsylvania 19105

The American farmer is known throughout the world as an innovator, being the first to grasp new farming concepts and aids and having the ability and perseverance to incorporate them into a more efficient and effective farming operation. These innovations have been going on since before the beginning of the industrial revolution, through the age when gasoline engines first replaced horses as the major source of farm power, through the age of the cotton gin, etc. I'm sure most of us remember or have seen the effects of the introduction of hybrid corn on the American farm. All of these changes have contributed to the American farmer's reputation as the world's supplier of food. Technological advances must not end here, especially during a time of depressed economic conditions when farmers need to continually improve productivity per acre to stay in business.

Wheat is one of the last untapped areas offering potential for research and new technology that will revolutionize current production practices, as it has in hybrid corn, hybrid sorghum, hybrid sunflowers, and numerous other hybrid crops. We have come to think of hybridization of crops as a revolutionary step for improving productivity per acre.

We are here today to discuss HYBREX(TM), a new technology from Rohm and Haas Company used in the production of higher yielding hybrid wheats. The HYBREX(TM) technology program offers parental inbreds, a chemical hybridizing agent, production know-how, technical service, and advertising/marketing support to local seedsmen already engaged in the production, marketing, and service to farmers in their general area.

Local seedsmen plant the parental inbreds in strips (very similar to hybrid corn) with the female strip normally being wider than the male strips. In the early Spring, the fields are sprayed with the HYBREX(TM) chemical that serves as a female pollen suppressant. At the same time, the usual fertilizer and weed control regimes are followed.

The female strips are harvested for hybrid seed while the male strips move into the commercial grain markets. Only the purest, best quality seed is conditioned and put in bags for sale to farmers. This seed is easily distinguished from other seed wheat because all hybrid seed wheat produced with HYBREX(TM) technology carries a HYBREX(TM) hybrid quality sticker on the bag.

HYBREX(TM) produced hybrid seed wheat has wrinkled seed similar to hybrid corn. Also, seed tends to be smaller, meaning that farmers can plant less pounds per acre and still get the same plant production. In fact, because of other factors, Rohm and Haas personnel recommend decreasing seeding rates as much as 25 to 40% depending on the area of the country. All in all, this makes hybrid seed wheat a bargain to the farmer.

Hybrids produced by HYBREX(TM) technology have been entered in 13 State yield trials last year and several more this year. Publication policies of universities prohibit republication of official yield trials; however, we encourage you to get copies of the official yield trials in your State and evaluate hybrid performance. A list of hybrids is shown in Table 1.

Table 2 shows a summary of the soft red winter wheat hybrids and Table 3 shows a summary for selected locations in the hard red winter wheat area. Further information is available from my listed address.

Rohm and Haas has HYBREX(TM) research centers and test sites located throughout the major wheat-growing areas of the United States. These centers are operated at a cost of several million dollars a year to support continued advances in hybrid seed wheat research.

In summary, we at Rohm and Haas Company believe that HYBREX(TM) technology offers another innovation that joins a long line of previous innovations used by the American farmer to improve productivity per acre. These improvements become increasingly important, especially during times of depressed prices and farm economy.

1) HYBREX is a trademark of Rohm and Haas Company

TABLE 1. HYBREX(TM) produced hybrid wheats entered in official State yield trials

| Soft Red Winter Wheat | Hard Red Winter Wheat |
| --- | --- |
| HW3006 | HW1001 |
| HW3007 | HW1010 |
| HW3008 | HW1019 |
| HW3014 | HW1020 |
| | HW1021 |
| | HW1024 |

Table 2. HYBREX™ produced hybrid seed wheat, compared to commonly grown varieties (Bu/Acres); 1982 selected data for the soft red winter wheat area.

| | Missouri | | Illinois | | | | | | | | | Indiana | | | Ohio | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hybrid | Dexter | Portage-ville | Fayette Co. | Pike Co. | Champaign | Brownstone | Urbana | Mt. Vernon | Richland Co | Charleston | New Win. | Hope | Randolph Co | Jennings Co | Van Wert | Ripley | * Averages | No. Locations |
| HW 3006 | 42 | 51 | 64 | 60 | 98 | 64 | 98 | 90 | | | | | | | | | 71 | 8 |
| HW 3007 | | | | | | | | 69 | 78 | 60 | 79 | 72 | 69 | 68 | 63 | 58 | 68 | 9 |
| HW 3005 | 35 | 45 | 64 | 51 | 95 | 64 | 95 | 75 | | | | | | | | | 66 | 8 |
| P-2550 | 37 | 51 | 61 | 54 | 98 | 61 | 98 | | | | | | | 68 | | | 66 | 8 |
| Caldwell | 36 | 45 | 61 | 60 | 95 | 61 | 95 | 61 | 76 | | | | 67 | 63 | | | 65 | 11 |
| Auburn | 31 | 43 | 61 | 52 | 100 | 61 | 100 | 58 | 62 | | | | 62 | 65 | | | 63 | 11 |
| M-1003 | 30 | 52 | 61 | 51 | 97 | 61 | 97 | 53 | 52 | | | | 64 | 66 | | | 62 | 11 |
| Pike | 30 | 47 | 55 | 50 | 93 | 55 | 93 | 65 | 71 | | | | 62 | 59 | | | 62 | 11 |
| Hart | 33 | 47 | 64 | 54 | 86 | 64 | | 65 | 71 | 52 | 55 | 70 | 64 | 68 | 62 | 52 | 60 | 15 |
| Arthur 71 | 24 | 42 | 51 | 46 | 81 | 51 | | 64 | 62 | | | | 61 | 61 | 59 | | 55 | 11 |
| S-76 | 30 | 47 | | | | | | 68 | | 50 | 57 | | 65 | | 59 | | 54 | 7 |

Table 3. HYBREX™ produced hybrid seed wheat, compared to commonly grown varieties (Bu/Acres); 1982 selected data for the hard red winter wheat area.

| Hybrid | Colorado | | | | | | | | | | Kansas | | | | | | | | Nebraska | | | | Oklahoma | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bennett | Matheson | Burlington | Burlington (Irr.) | Kim | Punkin Ctr. | Sterling | Rockford (Irr.) | Ovid | Platner | Minneola | Ft. Hays | Garden City | Tribune | Tribune (Irr.) | Hutchinson | Belleville | St. Johns | Northeast | Southwest | Northwest | South Central | Lahoma | Altus | * Averages | No. Locations |
| HW 1001 | 32 | 38 | 69 | 81 | 26 | 24 | 44 | 100 | 63 | 54 | 38 | | 24 | 49 | 73 | 67 | 53 | 56 | 43 | 72 | 48 | 41 | 61 | | 53 | 22 |
| HW 1010 | 32 | 42 | 71 | 90 | 26 | 23 | 48 | 110 | 69 | 54 | 34 | 62 | 22 | 50 | 74 | 63 | 62 | 39 | | 69 | 61 | 42 | 65 | 65 | 55 | 23 |
| HW 1007 | | | | | | | | | | | | | 13 | 40 | 72 | 55 | | 58 | | | | | 59 | 53 | 50 | 7 |
| Vona | 33 | 48 | 70 | 86 | 31 | 20 | 38 | 110 | 69 | 51 | 34 | 61 | 23 | 46 | 68 | 64 | 67 | 53 | | 70 | 59 | 40 | 64 | 52 | 55 | 23 |
| Newton | 38 | 36 | 62 | 77 | 22 | 20 | 48 | 100 | 67 | 46 | 33 | 58 | 18 | 43 | 68 | 57 | 53 | 27 | | | | | | | 49 | 18 |
| Bennett | | | | | | | | | | | 36 | 61 | 25 | 45 | 60 | 52 | 35 | 36 | 40 | | | 31 | | | 42 | 10 |
| Hawk | 33 | 47 | 73 | 86 | 25 | 20 | 38 | 101 | 64 | 49 | 29 | 59 | 26 | 49 | 63 | 64 | 47 | 66 | | 67 | | 21 | 58 | 56 | 52 | 22 |
| Brule | 40 | 42 | 62 | | 27 | 22 | 48 | 90 | 69 | 43 | | 66 | | 40 | | | | 58 | 37 | 61 | 60 | 52 | | | 51 | 16 |
| Agate | 43 | 43 | 61 | | 30 | 25 | 45 | | 59 | 50 | | | | | | | | | 30 | | 47 | | | | 43 | 10 |
| Rocky | 35 | 49 | 66 | | 26 | 19 | 36 | | 59 | 48 | | 61 | | | 56 | | 38 | | 41 | 61 | 50 | 36 | | | 46 | 15 |
| NK 817 | 30 | 39 | 62 | 77 | 23 | 17 | 39 | 81 | 68 | 43 | 45 | 61 | 24 | 40 | 72 | 57 | 42 | 51 | | 62 | 57 | 43 | | | 49 | 21 |
| NK 835 | 29 | 44 | 73 | | 25 | 18 | 40 | | 63 | 46 | 39 | 63 | 22 | 40 | 73 | | 58 | 48 | | 62 | 55 | 45 | 61 | 41 | 47 | 20 |
| Tam 105 | 37 | 37 | 72 | 95 | 26 | 23 | 45 | 106 | 68 | | 38 | 60 | 30 | 47 | 73 | 67 | 60 | 40 | | | | | 59 | 55 | 55 | 19 |
| Scout 66 | | | | | | | | | | | 35 | 50 | 21 | 41 | 58 | 61 | 37 | 45 | 34 | 54 | 36 | 37 | 48 | 41 | 43 | 14 |
| Centurk | 31 | 43 | 60 | 65 | 27 | 17 | 37 | 84 | 59 | 46 | 32 | 60 | 20 | 44 | 57 | 64 | | | 34 | 64 | 48 | 32 | 57 | 42 | 47 | 22 |

# FUTURE OF HYBRID WHEAT BY MEANS OF CYTOPLASMIC MALE STERILITY AND GENETIC FERTILITY RESTORATION

Charles Hayward
Research Director, Department of Cereal Seed Breeding
Pioneer Hi-Bred International, Inc.
Hutchinson, Kansas

Of all grain crops capable of being hybridized, wheat has required the longest research effort. Many of the problems encountered in hybridizing wheat can be attributed to the genetic complexity of the wheat plant and to its self-pollinated nature.

Today, wheat breeders do have an effective cytoplasmic-genetic system of male sterility and pollen fertility restoration for producing hybrids in most wheat genotypes. Developing restorer lines (R-lines) capable of restoring complete fertility under widely varying environments has been a major challenge. Although we have confidence in the effectiveness of the biological systems involved, problems remain to be solved before a wide acceptance of hybrid wheat is anticipated.

Early hybrids were disappointing in yield production and often in other agronomic traits due to inadequacies of the inbred lines making up the hybrids. Present day hybrids show promise in appearance and performance. Larger numbers of high yielding inbreds, that equal or exceed the best pure line varieties, are making their appearance and are being tested in hybrid combinations. Combining ability studies are being expanded in order to determine which inbreds are best suited for the hybrid program. A strong conventional pure line (B-line) breeding program is an essential prerequisite for a strong hybrid program because this is the source of inbreds.

Advancements are being realized in changing the morphology of the wheat plant so it has better adaptation to cross-pollination. Good progress has been made in selection for larger and better extruding anthers and for florets that open up better. These improvements are direly needed to improve seed set and lower present day seed production costs. While major problems remain in hybrid seed production, many have been solved or minimized. Several of these problems are common for hybrid seed production regardless of hybridization technique. Hybrid seed production costs continue to be a major deterrent in hybrid wheat acceptance.

Data from heterosis (hybrid vigor) studies continue to be impressive. In 1981-82 trials, the average hybrid yield levels varied from 0 to 17 and -9 to 15 percent of the mid-parent and high-parent, respectively.

In a special heterosis study conducted at the Hutchinson station in 1981-82, 40 hybrids and their respective inbreds were evaluated for maturity, height, lodging, test weight, and yield. Inbreds representing fairly wide genetic diversity were selected for inclusion in the study. Hybrid yield levels varied from -13 to 46 and -16 to 35 percent of mid-parent and high-

parent, respectively. In general, and as expected, hybrids made up of more diverse inbreds exhibited the most heterosis. However, there were exceptions. Mid- and high-parent heterosis values are meaningful in predicting the success of hybrid wheat providing the yield of the parents (inbreds) is comparable to the yields of the best pure line varieties available.

Perhaps the flexibility and complementation aspects of hybrid wheat have as much potential value as heterosis itself. By cataloging inbreds for their specific merits, hybrids could be changed rapidly as the need arises. For example, one inbred can complement the weakness of the other, such as carrying a dominant gene for specific disease resistance. Through complementation it might be possible to combine two totally unacceptable inbreds (pure lines) into an acceptable, top performing hybrid.

Research efforts are continuing in the development of additional biological systems. Hopefully we can find systems or develop ones that are less genetically complex and easier to use than what we have available. We are evaluating different hybridizing techniques, including chemical. There are advantages and disadvantages to the different systems. More data are needed before final judgment can be made on the best system(s) to use for hybridizing wheat. Economics, production, and performance are the keys.

The monetary return the farmer can expect from hybrids over varieties remains the ultimate determining factor in hybrid wheat success.

# HYBRID WHEAT RESEARCH IN THE PUBLIC SECTOR

K. A. Lucken
North Dakota State University
Fargo, North Dakota

Successful commercial production of hybrid wheats will require 1) reliable control of male fertility and male sterility in hybrid parents and in their hybrids by either genetic or chemical means; 2) high and relatively stable hybrid seed yields through cross-pollination in seed production fields; and 3) male and female parents whose hybrids will have a significant yield advantage over conventional wheat varieties. These requirements have been the basis for extensive research during the past 20 years by both public and private researchers. The commercial companies have had the largest, most comprehensive programs--with strong breeding efforts to develop hybrid parents and to test hybrid performance. They also have conducted extensive field-scale research to determine optimal procedures for producing hybrid seed. Public research has been focused on detailed studies of problems judged to be critical to hybrid development. These problems have ranged from the inheritance of fertility restoration to measurements of pollen production by wheat varieties and to the performance of hybrids produced by hand-crosses, to name a few, and have often been done by M.S. or Ph.D. candidates for their thesis research. Although some wheat varieties developed by public institutions can be used directly as hybrid parents, the limited availability of elite male sterile and restorer parents from public breeding programs has restricted the rate of progress in hybrid wheats.

# IMPROVING HYBRID WHEAT YIELDS THROUGH CULTURAL PRACTICES

Dr. Bill J. Roberts
Manager, Cargill Wheat Research Program
Cargill, Inc.
Fort Collins, Colorado

Some speakers have talked about the yield improvements possible through the inherent genetic potential of hybrid wheat. I would like to discuss briefly another area that I believe is equally important and one in which there is still much to learn. I'm referring to the yield potential of hybrids possible from improvements in cultural practices.

As many of you are aware, Cargill began marketing four hard red winter hybrid wheats on a limited basis this fall. These are the first commercially available wheat hybrids to be marketed by Cargill. The four hybrids are the result of a 16-year program to find, incorporate, and evaluate genetic materials obtained throughout the world that would improve wheat yields. Farmers in the hard red wheat production areas of Kansas, Oklahoma, Colorado, Texas, and Nebraska seeded the new hybrids this fall. They are marketed under the BOUNTY brand name.

Yield data for our 1982 hybrids and results from State trials and about 300 farmer cooperators show hybrid yield improvements of up to 10 bushels per acre or 20 percent over the top varieties. But we're even more encouraged by results from hybrids now being tested that should be available in 1983 or 1984. These hybrids show a 5 to 10 percent additional yield increase, so it's the upward trend that's important.

Such figures show why we are pleased with the hybrid yields obtained in our research trials. But there is another reason for optimism. I am confident that dryland wheat producers can improve hybrid yields by a minimum of 5 percent by improving their management practices. Irrigators can improve yields by a minimum of 10 percent. Hybrid wheat is a new crop with new challenges. There is much to learn. I believe we've barely scratched the surface concerning cultural management of hybrids.

As part of Cargill's effort to learn more about cultural practices, our technical service representatives worked with cooperating farmers the past two years using a performance evaluation system called Product Evaluation Program or PEP. The program is commonly used to assist corn producers, but it's used to evaluate other crops, too. PEP is designed so that farmers plant consistent patterns of a check hybrid to compare it with other hybrids or varieties. An adjusted yield that takes field variability into account then is computed. Net profit per acre is calculated based on yield and grain moisture.

The program provided a broad base of performance information concerning how wheat yields were affected by many seeding rates, fertilizer programs, moisture conditions, geographic locations, and other environments. The

information has confirmed our belief that hybrid wheat will give the biggest return to wheat growers who want to fine-tune their cultural practices.

Because seed supplies now are limited, we are recommending that producers plant hybrids on their best land. That's because a simple calculation shows that a 20 percent yield increase for hybrid wheat on ground that usually produces 30 bushels per acre equals six extra bushels. But a 20 percent yield increase on ground that usually produces 60 bushels equals 12 extra bushels.

Farmers who raised hybrids the past two years made observations that would be expected from any hybrid when it was compared with varieties. The hybrids were more vigorous, had more lush growth, withstood drought and other stresses better, and recovered faster when grazed. Producers also found that proper management practices, like adjustment of drills so wheat is seeded at correct rates, are important. Some producers didn't get enough seed in the ground because of the larger seed sizes of some hybrids. This obviously wouldn't allow for maximum yield potential. We generally recommend that drills be adjusted so at least 50 pounds of seed are planted per acre with larger seed sizes.

In summary, I am pleased with the yields made possible by the genetics we incorporated into our new hybrids. But I believe there is much potential to boost yields even more by further refinement of cultural practices.

The same opportunity was present during the adoption stages of other hybrid crops. Development of hybrid wheat is not the end of our work. In many respects, it's the beginning. The work of refining cultural practices and developing better hybrids is in its infancy.

# POTENTIAL FOR INCREASE IN WHEAT WINTERHARDINESS

John R. Erickson
Hybritech Seed International, Inc.
Wichita, KS 67203

The requirement for winterhardiness in wheat varies from region to region and from year to year within a region depending on the prevailing climatic conditions. Choice of winterhardiness level in a variety should be based on long term conditions and the degree of risk a grower is willing to assume. Growing a less winterhardy variety with greater yield potential may be possible if good management practices are utilized.

Different areas in the United States may suffer winter damage for different reasons. The direct effect of low temperature and desiccation are more common in the semi-arid Great Plains than in other areas. Damage from soil heaving and smothering under ice, however, occur more frequently in humid regions.

There is substantial variation for winterhardiness within cultivated wheat. The most winterhardy variety presently available is Norstar, from Alberta. Many different varieties are available, however, with levels of winterhardiness appropriate to their area of production. These generally give satisfactory performance unless they are seeded in areas where they are not adapted.

The Northern Plains area primarily grows spring wheats because the severity of the winter makes winter wheat production hazardous. I evaluated most of the winter wheats in the USDA World Collection and found the USSR and North America to have the higest percentage of winterhardy germplasm. A number of accessions were found that had a higher winterhardiness level than the most winterhardy varieties being grown. These accessions have been used for breeding purposes, that is, Alabaskaja is one of the parents of Norstar. Appropriate crosses involving these winterhardy accessions and good selection practices may provide new varieties with improved winterhardiness.

Significant additional improvements in winterhardiness may have to come from rye or other wheat relatives. Although rye and some other species related to wheat are more winterhardy than wheat, it has not yet been possible to transfer their superior winterhardiness to wheat. Improved genetic engineering techniques may permit wider crosses to be made. However, once these crosses to other species are made extensive additional breeding and selection probably will be required to develop wheats with superior winterhardiness.

Most areas of the United States have wheat varieties available with generally adequate levels of winterhardiness. Good management practices, such as optimum seeding date and rate, firm seedbed preparation, and use of proper seeding equipment reduce the risk of winter damage. In extremely cold areas, seeding into standing stubble usually will provide the necessary protection for successful winter wheat production.

# HEAT AND DROUGHT TOLERANT WHEATS OF THE FUTURE

E. L. Smith
Oklahoma State University
Stillwater, Oklahoma

Good progress has been made over the years in breeding wheat varieties with increased tolerance to drought and heat stress. Modern varieties are more productive in stress environments than older wheat varieties. In Oklahoma, where drought stress constitutes a serious constraint to wheat production, state average yields have increased dramatically since the 1930's (see figure 1). Based on 5 year averages, yields have increased from 21.9 bu/A in 1961 to 30.0 bu/A in 1980. Upon making comparisons between long-term checks and newer varieties during this 20 year period, we learn that more than half of this increase is due to genetic improvement. Similar patterns in variety improvement are found in most of the stress-prone wheat production areas of the U.S.A. So far, breeding for tolerance to drought stress has been accomplished by empirical methods rather than by the use of sophisticated analytical techniques. Breeders have slected new lines on the basis of yield level and test weight value in test locations in which drought stress occurs. Considrable interest has also been given to increased head size and increased kernel weight for stability of production in semiarid regions (6). We have all waited in great expectation for new analytical selection techniques from the physiologists, but these have been slow in coming.

There has been a substantial increase in the number of physiological oriented studies on drought tolerance during the past few years. We have learned some new facts, but we still don't know very much about heat and drought tolerance. According to Passioura (5), attempts by breeders and physiologists to collaborate in the development of stress tolerant varieties have not been very successful. Even so, the potential benefits to be gained by such collaboration are enormous and interaction between breeders and physiologists should be encouraged.

Drought stress and heat stress can be considered together in many instances, but not always. Wheat standing in water in western Oklahoma in late spring, for example, occasionally shows severe heat stress symptoms. However, since drought seems to be, by far, the more serious constraint of the two, this report will deal mainly with drought stress. From the standpoint of plant breeding, we are not really interested in drought resistance *per se*. What we want is a wheat plant that has a useful level of drought tolerance. What we want is a plant that has the inherent capacity to minimize yield loss under stress conditions and at the same time, has the ability to produce high yields under good conditions.

The response of genotypes to various environment conditions tells us something about how the production capabilities of a variety changes from good environments to stress environments. The genotype-environment regression

model proposed by Eberhart and Russell (2) provides a good method of characterizing production characteristics of a set of varieties. Using yield data from wheat performance tests grown in Oklahoma over the past 12 years (1971-82) we found that the regression technique provides good predictive values for genotype response to environment conditons when certain 'rogue' environments were eliminated from the analysis (7). Results from a number of winter wheat regression studies suggests some trends with regard to general production characteristics: older varieties appear to be more productive under severe drought stress conditions, but are less productive than modern varieties under good conditions. Thus, the older types are more stable than newer varieties, but are less productive over a wide range of growing conditions.

The ideal situation would be to have a highly stable genotype with high yield characteristics. (See figure 2 for a generalized representation of genotype stability.) But this ideal situation may be difficult to achieve. High yield potential tends to be associated with low stability. In our 12-year study in Oklahoma, we looked at the correlation between Yi (mean yield) and Bi (regression stability) in four, three-year periods. The correlation (r values) were 0.579*, 0.483, 0.891**, and 0.864* respectively for the periods 1971-73, 1974-76, 1977-79, and 1980-82 (7). During the last two periods, 1977-79 and 1980-82, short-statured, productive genotypes were the predominant types in the tests. The results suggest that higher yield potential was made at the expense of stability. A consensus appears to be building that we should be seeking the 'middle of the road' type wheat variety. This type of variety would have high yield potential in all environments except with extremely high or extremely low production conditions. This reasoning is based on the fact that extreme growing conditions, either high or low, occur less frequently than environmental conditions in the intermediate ranges.

New thrusts in the development of drought tolerant wheats will, no doubt, come with renewed efforts in collaborative programs between breeders and physiologists. Interaction between breeders and physiologists is essential if new yield levels are to be achieved. The total above-ground part of the wheat plant (biological yield) in a water-limited production area is directly related to the water supply. Biological yield offers little hope of modification through breeding. Harvest index, on the other hand, which reflects the ratio of grain to total biological yield, appears to be amenable to genetic improvement for enhanced drought tolerance. As a concept, harvest index could be used to study the effects of various morpho-physiological traits interacting with stress conditions (5). An examination of the components of harvest index might lead to a better understanding of drought stress. A number of morpho-physiological traits are under investigation at the present time (3). A listing of these is presented in Table 1.

It appears that several new techniques now being developed by physiologists could play an important role in breeding for dought tolerance: Techniques are becoming available for the rapid measurement of leaf canopy temperatures on a scale consistent with the needs of the plant breeder (1). Canopy temperatures reflect the effects of stress, but it has as yet not

been determined whether high temperatures or low temperatures are desirable.

Root measurements can be handled fairly efficiently on wheat seedlings grown in sand culture. Significant differences are found among genotypes, but the optimum pattern of root development remains to be determined (4). No doubt, different climatic zones and types of soils will require slightly different rooting patterns for enhanced drought tolerance.

It is possible that more rapid techniques can be developed for measuring leaf water potential. Sojka et al (8) reported that wheat genotypes with higher water potentials showed less yield reduction. Research is underway to develop more rapid methods of measuring leaf water potential by utilizing correlated traits.

Wide hybridization as a means of breeding for drought and heat tolerance should be re-examined. Stress tolerant traits exist in some of the wild relatives of wheat, notably in the genus Agropyron. As physiological screening techniques are developed and improved, the transfer of stress tolerant gene systems from alien species should take on a more important role.

In any event, the chances are good that continued collaboration between plant breeders and physiologists will result in significant break-throughs in the realm of drought tolerance. Research will move forward from its present base to the benefit of wheat producers in drought-prone areas.

## Literature Cited


1. Blum, A. (1983). Genetic and physiological relationships in plant breeding for drought resistance. Agric. Water Manage. (in press - to be published in 1983).

2. Eberhart, S. A., and W. A. Russell. 1966. Stability parameters for comparing varieties. Crop Sci. 6:36-40.

3. Johnson, R. C. 1982. Personal communication, Oklahoma State University.

4. Merkle, O. G. 1982. Personal communication, Oklahoma State University.

5. Passioura, J. B. 1981. The interaction between the physiology and the breeding of wheat. p.191-201. In L. T. Evans, and W. J. Peacock (ed.) Wheat science - today and tomorrow. Cambridge Univ. Press. Cambridge.

6. Smith, E. L. 1976. The genetics of wheat architecture. Ann. Oklahoma Acad. Sci. 6:117-132.

7. Smith, E. L., and M. Tahara. 1982. Unpublished data. Oklahoma State University.

8. Sojka, R. E., L. H. Stolzy, and R. A. Fischer. 1981. Seasonal drought response of selected wheat cultivars. Agron. J. 73:838-845.

Table 1. Some morpho-physiological traits related to drought tolerance in wheat that are amenable to genetic modification.

| |
|---|
| Leaf (canopy) temperature |
| Cell osmotic adjustment |
| Cell membrane stability |
| Leaf rolling index |
| Leaf water potential |
| Tiller survival |
| Root systems |
| Stomatal resistance |
| Root:shoot ratio |

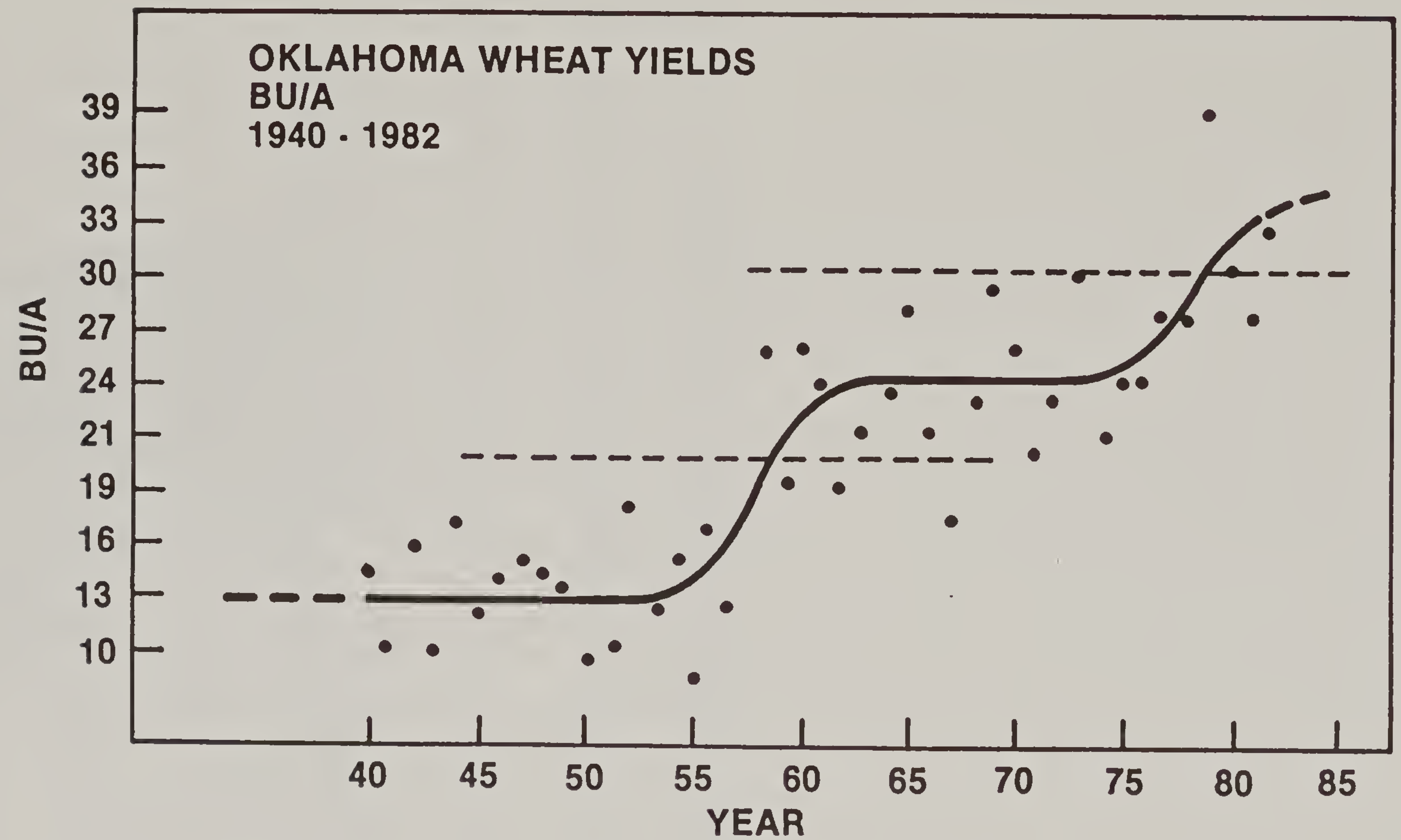


Fig. 1. Oklahoma wheat yields, 1940-1982.

Regression line 'A' represents a genotype with above average stability and below average mean yield. Many of the older, standard height varieties fall into this category.

Regression line 'B' represents a genotype with below average stability and above average mean yield. Many of the newer, semi-dwarf varieties fall into this category.

Regression line 'C' represents an 'ideal' genotype with average stability and above average yield.

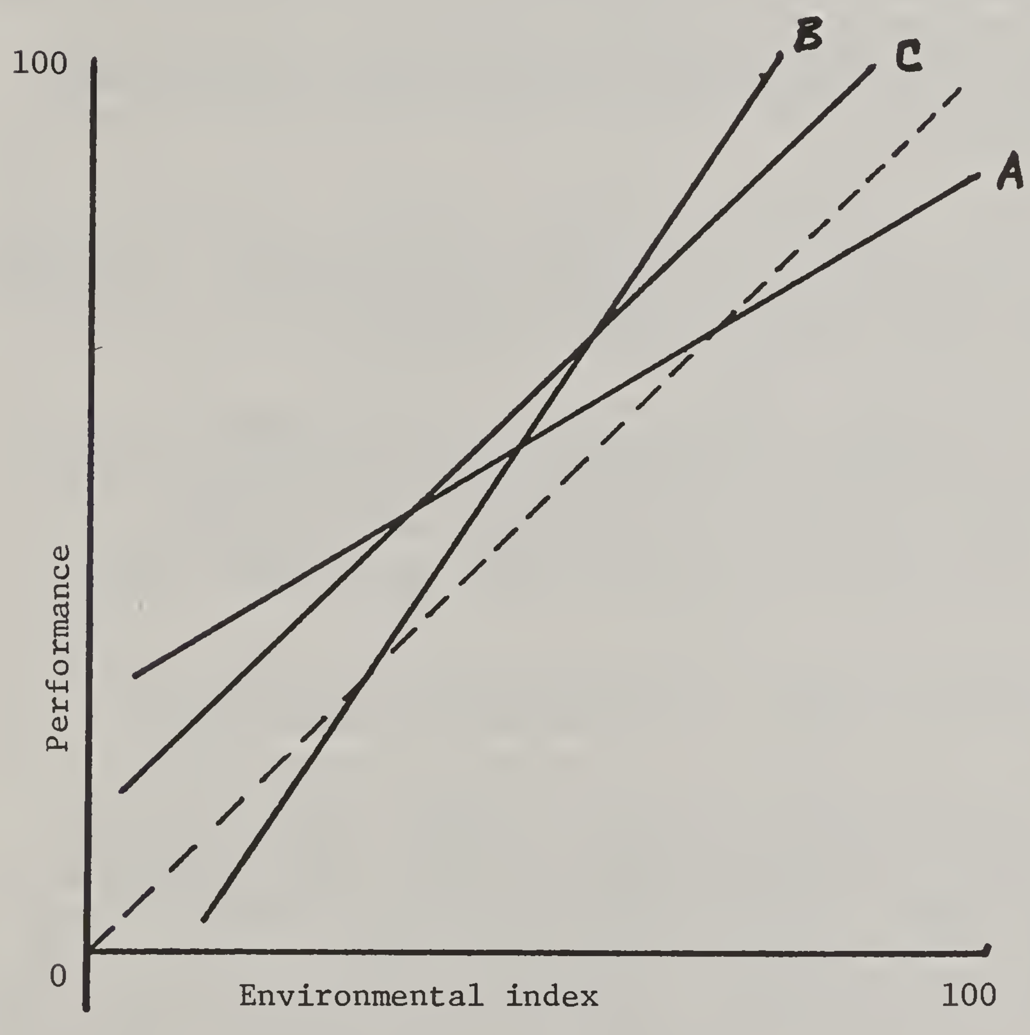


Fig. 2. Generalized representation of yield stability for different categories of genotypes.

# BREEDING FOR ENHANCED GRAIN PROTEIN AND END USE QUALITY

V. A. Johnson, S. L. Kuhr and P. J. Mattern
Leader Wheat Research, Agricultural Research Service,
U. S. Department of Agriculture;
Assistant Professor and Professor,
Department of Agronomy, University of Nebraska,
Lincoln, Nebraska

The quantity and quality of protein in wheat grain exert a major influence on the nutritional value of the wheat as well as its suitability for bread-making and other end uses. Historically, preoccupation with protein in wheat was based on its contribution to processing and end use products. A high quality bread wheat, therefore, was one that produced grain that would mill satisfactorily and contained the kind and amount of protein to permit good bread to be baked from it.

For the many people in the world who rely on wheat as a dietary mainstay, the nutritional value of the wheat is an important consideration. Nutritional value is largely determined by the amount and composition of the protein in wheat grain. Wheat also is an important source of minerals.

Quality traits like all other traits of wheat are under genetic control and can be manipulated by breeding. Most quality traits also are strongly influenced by production environment. Variation caused by environment can exceed genetic variation for such traits as yield and protein content. Breeding improvement becomes much more difficult when environmental variation is large.

The Agricultural Research Service in cooperation with the Nebraska Agricultural Experiment Station has conducted research on wheat protein since 1960. The research was undertaken to elucidate the genetic basis for protein differences in wheat and establish the relationship of protein quantity and quality with grain yield and other agronomic and quality traits. An International Winter Wheat Performance Nursery (IWWPN) grown annually at sites in all major winter wheat-producing countries was established in 1969 as a part of the project. The research was supported largely by funds from The Agency for International Development (AID) and ARS during the period from 1966 to 1979. Since 1979, ARS funds have permitted continuation of the work, including the international evaluation network. Our major research findings will be summarized.

Numerous genes that influence the level of protein in wheat grain have been detected among germplasm from diverse areas of the world. Genes with major effect have been identified in Atlas 50 and Atlas 66, which were derived from the Brazilian variety Frondoso, and in Nap Hal, a wheat introduction from India. Genes with relatively smaller effect appear to be numerous among wheat varieties. Plainsman V and Century II developed by Seed Research Associates in Kansas carry protein genes believed to be derived from *Aegilops*.

Recently, collections of the wild wheat species Triticum dicoccoides in Israel have been shown to produce seed with very high protein content which is being transferred to cultivated wheat.

ARS-Nebraska research also has explored the variation of amino acids in wheat protein. The nutritional value of wheat protein is determined by the amount and availability of essential amino acids in relation to man's requirements. Among these, lysine is in shortest supply in wheat and reduces the nutritional quality of wheat protein. Only limited genetic variation for lysine among wheats in the World Collection was detected. Because of this and because the amount of lysine and other essential amino acids in wheat grain can be increased by increasing the protein content of wheat, our research at Nebraska has emphasized increased protein content.

High yield in wheat tends to be associated with depressed protein content of the grain. Although most studies have reported significant negative correlations of the two traits, only a relatively small part of the protein variation can be explained by variation in yield. Internationally, the need for carbohydrates is fully as great as the need for protein in most developing countries. In fact, the two needs are so closely related that the protein deficiency of an undernourished person cannot be corrected without first satisfying his requirement for calories. Clearly then, the negative relationship of yield and protein is a basic problem in protein breeding and has led to the rejection by some breeders of protein improvement as a major breeding objective. Further, the literature contains reports that high protein in wheat is associated with small or shrivelled seed; that semi-dwarf varieties, because of shorter straw, are likely to be low in protein; and that lower energy requirements of carbohydrate synthesis compared with protein synthesis, of necessity, will cause varieties with elevated protein to be less productive than lower protein varieties. The extremely poor milling and baking characteristics of initial genetic sources of high protein have led some breeders to believe that elevated protein may not be compatible with good processing characteristics.

We successfully transferred one of the protein genes from Atlas 66 to the hard red winter wheat variety Lancota which was released to growers in 1975. In regional trials from 1972-1974 Lancota exhibited combined high productivity with above-average protein content (Figure 1). Although Lancota produces large seed and has excellent milling and baking properties, its tall plant height, moderately late maturity, and relatively narrow adaptation have discouraged wide-scale grower acceptance of Lancota.

Crosses of Atlas 66 with Nap Hal provided evidence that they carry different genes for protein. Lines were readily selected from the crosses that were higher in protein than either parent. However, all were weak-strawed, nonproductive, produced poor seed, and were agronomically unacceptable. Were these lines high in protein merely because of their poor seed and low productivity or could these traits be separated through further hybridization?

Recent data from replicated irrigated trials at Yuma, Arizona have provided useful information. The performance of six winter lines is compared with that of the check variety TAM 105 in Table 1. Three were significantly more productive, produced significantly larger seed, and were significantly higher in protein content than the check. All but one was as short or shorter than TAM 105. Seventeen of 60 entries in the trial equalled TAM 105 in yield but were significantly higher in protein content. The pedigrees of the lines in Table 1 are shown in Table 2.

The performance of eight spring lines is compared with that of the check variety Super X in Table 3. All were equal to Super X in yield but were significantly higher in protein content. Some were equal to or larger than Super X in seed size and were as early and short-strawed as Super X. All of the 70 entries in the trial were higher than Super X in protein but only 22 were equal in yield to Super X. Only a few of the lines possess acceptable mixing time and tolerance for bread wheat. Pedigrees of the lines in Table 3 appear in Table 4.

All of the winter and spring experimental lines in the 1982 replicated tests at Yuma were distributed internationally in a High Protein-High Lysine Observation Nursery. In 1982 the seed was sent to cooperators at 49 sites in 30 countries for evaluation and use in breeding. Similar material is distributed annually by the ARS-Nebraska group.

Recent M.S. degree research at the University of Nebraska by C. J. Peterson revealed high positive correlations of several trace mineral elements with protein content of wheat (Table 5). Seed from twenty-seven varieties grown in the 1980 IWWPN at six sites was analyzed. Highly significant differences among varieties in trace mineral content were detected. The mineral differences primarily reflected seed protein differences among the varieties. Higher levels of minerals in wheat flour associated with elevated protein constitute an additional nutritional benefit.

A serious constraint to breeding for higher protein in wheat is lack of laboratory facilities for rapid protein analyses at many breeding stations. We are currently evaluating an inexpensive system for separating wheat seed on the basis of protein content. The technique, which was developed by Mr. A. Garzon Trula, Office of the Director General for Farm Production, Ministry of Agriculture in Madrid, Spain and reported in a study entitled "Basics of Seed Densimetry" in 1981, is based on solvent flotation. Starch density of wheat is 1.6 g/ml compared with protein density of 1.2 g/ml. Protein absorbs approximately five times more $H_2O$ than starch when the seed is soaked in $H_2O$ for 10 days or more. If the soaking is done at 0° to 1° C, germination is inhibited and seed remains viable. Following soaking, high protein seed can be separated from lower protein seed in a solvent solution of carbon tetrachloride and hexane. Presoaking in $H_2O$ prevents the solvent from penetrating the seed and interfering with germination. Following separation the seed fractions can be air dried without loss of viability and can be seeded normally.

We believe the technique has exciting possibilities for inexpensive recovery of high protein seed from bulk hybrid populations known to be segregating for protein. The only apparatus required for the procedure is a small chamber in which temperature can be controlled at 0° to 1° C and ventilation is necessary to remove solvent fumes during flotation. The technique also requires that shrivelled kernels be removed from the bulk since these would separate with the high protein fraction and are not likely to be genetically high in protein. The efficiency of separation is shown in Tables 6 and 7.

We believe that we now have combinations of genes for high protein in productive, large seeded, agronomically attractive germplasm. It represents significant improvement over the earlier nonproductive tall high protein varieties like Atlas 66, Nap Hal, and their first breeding cycle derivatives. Our germplasm has been and will continue to be shared with breeders from all countries.

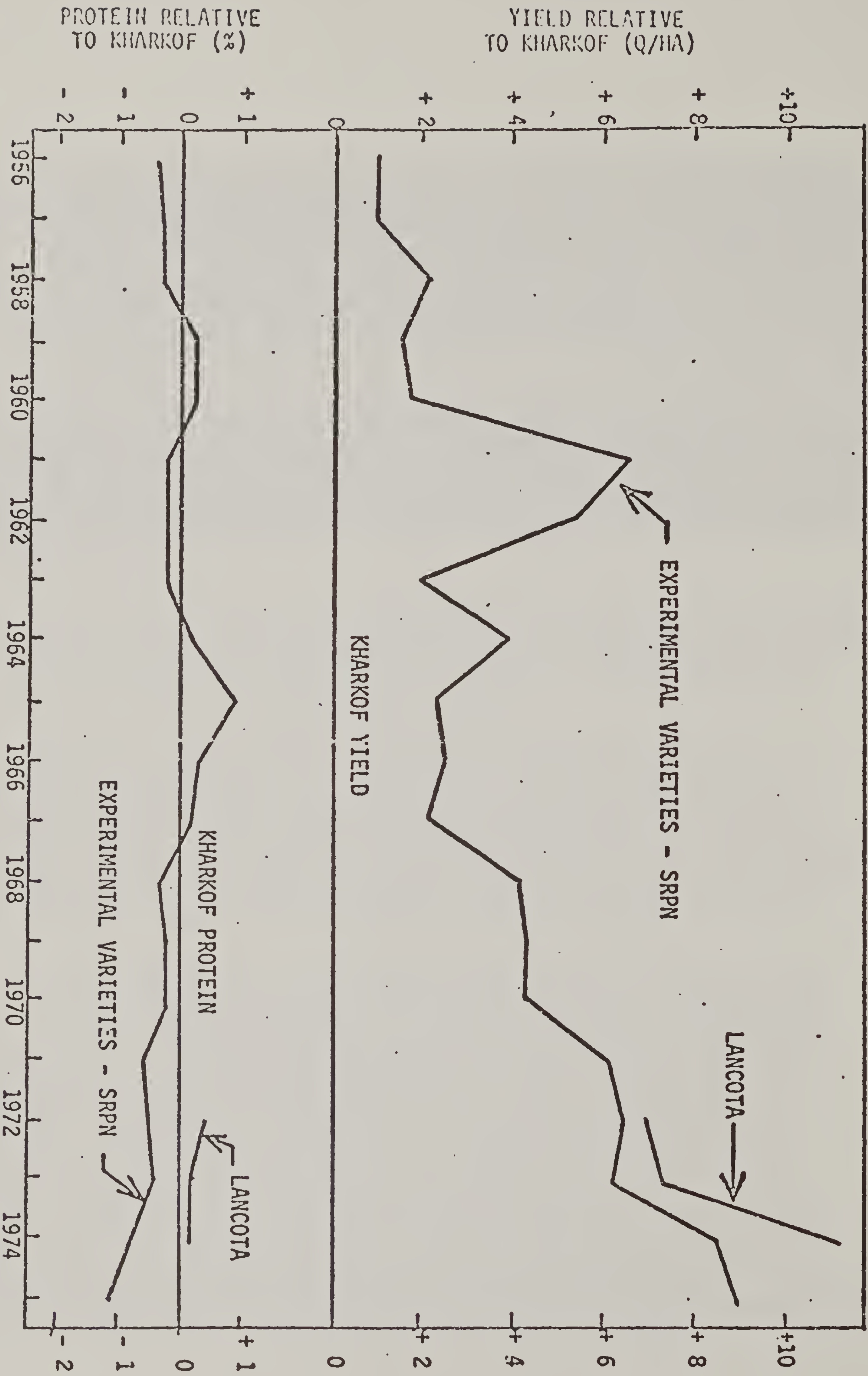


Figure 1. Yield and protein trends in the Southern Regional Performance Nursery (SRPN) relative to the check variety Kharkof and performance of Lancota during the 1972-74 testing period in the nursery.

Table 1. Promising high protein winter wheat lines in replicated irrigated trials, Yuma, Arizona, 1982.

| Entry | Maturity | Plant height | 100-seed weight (g) | Grain yield (q/ha) | Grain protein (%) |
|---|---|---|---|---|---|
| 33 | ME | M.sh. | 3.5 | 64.6 | 13.3 |
| 28 | E | Med. | 4.3 | 52.8 | 16.3 |
| 24 | E | Sh. | 3.8 | 50.4 | 16.2 |
| 35 | E | M.sh. | 3.9 | 48.6 | 15.6 |
| 25 | E | Sh. | 4.0 | 45.4 | 16.1 |
| 27 | E | M.sh. | 3.8 | 41.2 | 18.2 |
| TAM 105 | ML | M.sh. | 3.1 | 37.0 | 13.0 |
| $LSD_{0.05}$ | -- | -- | 0.5 | 9.9 | 2.0 |

Table 2. Pedigrees of promising high protein winter wheat lines in replicated trials, Yuma, Arizona, 1982.

| Entry | |
|---|---|
| 24 | At66/Nap Hal//Bezostaya 1 |
| 25 | At66/Nap Hal//Bezostaya 1 |
| 27 | Nap Hal/At66//Lovrin 12 |
| 28 | Nap Hal/At66//Lovrin 12 |
| 33 | F53-70//Nap Hal/CI13449 |
| 35 | Rannaya//CC-INIA/CNO-S. Cerros |

Table 3. Promising high protein spring wheat lines in replicated irrigated trials, Yuma, Arizona, 1982.

| Entry | Maturity | Plant height | 100-seed weight (g) | Grain yield (q/ha) | Grain protein (%) |
|---|---|---|---|---|---|
| 15 | L | MT | 3.8 | 62.1 | 15.6 |
| 5 | Med | M.sh. | 2.8 | 61.6 | 16.2 |
| 17 | ME | Med. | 5.0 | 58.2 | 15.8 |
| 7 | ML | Med. | 3.2 | 56.7 | 16.8 |
| 33 | E | Sh. | 4.6 | 51.4 | 16.9 |
| 31 | ME | M.sh. | 4.4 | 51.2 | 16.4 |
| 42 | E | M.sh. | 3.7 | 51.1 | 16.7 |
| 35 | E | Sh. | 3.1 | 49.0 | 17.8 |
| Super X | E | Sh. | 4.3 | 52.6 | 13.2 |
| $LSD_{0.05}$ | - | - | 0.4 | 10.9 | 1.5 |

Table 4. Pedigrees of promising high protein spring wheat lines in replicated trials, Yuma, Arizona, 1982.

| Entry | |
|---|---|
| 5 | At66/Nap Hal//Nord Desprez 2 |
| 7 | Nap Hal/CI13449//CC-INIA/CNO-S. Cerros |
| 15 | TR535/5/MV69-05/4/Cmn/Ot//At66/Cmn/3/ Homestead |
| 17 | Nap Hal/CI13449//Ifmg No. 3 |
| 31 | Nap Hal/At66//Sort 12-13/3/NE7060 |
| 33 | Nap Hal/At66//Sort 12-13/3/NB68513/ Zg 1501-69 |
| 35 | Nap Hal/At66//Sort 12-13/3/NB68513/ Zg 1501-69 |
| 42 | At66/Nap Hal//Skorospelka 35/NE701137 /5/Sel 14-53/3/Lcr//At66/Cmn/4/ $CNO^2$-INIA/Bb |

Table 5. Simple and genetic correlations of grain protein content with mineral levels in flour and bran[a/].

| Mineral element | Flour: Simple | Flour: Genetic | Bran: Simple | Bran: Genetic |
|---|---|---|---|---|
| Calcium | .55** | .21 | .76** | -.25 |
| Phosphorus | .37** | .88 | .03 | .48 |
| Iron | .59** | .94 | .69** | .46 |
| Magnesium | .35** | .89 | .22** | .13 |
| Zinc | .73** | .95 | .44** | .55 |

a/ M.S. Thesis, C. James Peterson, "Evaluation of variation in trace mineral levels of wheat grain using X-ray fluorescence spectrometry", University of Nebraska, 1982.

Table 6. Separation of high protein from low protein seed by solvent flotation.[a]

| | | Protein content (%) |
|---|---|---|
| Lab. Sample 1 | Original sample | 13.6 |
| | High protein fraction | 15.4 |
| | Low protein fraction | 10.9 |
| | Mid-fraction | 12.9 |
| Lab. Sample 2 | Original sample | 13.1 |
| | High protein fraction | 15.1 |
| | Low protein fraction | 11.2 |
| | Mid-fraction | 13.0 |

[a] Based on method of Mr. A. Garzon Trula, Ministry of Agriculture, Madrid, Spain.

Table 7. Separation of high protein from low protein seed in bulk hybrids by solvent flotation.[a]

| Population | Protein content (%) | |
|---|---|---|
| | High protein fraction | Low protein fraction |
| Experimental Hybrid | | |
| 1 | 19.0 | 16.1 |
| 2 | 18.1 | 16.3 |
| 3 | 17.2 | 15.2 |
| 4 | 18.6 | 13.8 |
| 5 | 17.4 | 14.3 |
| 6 | 18.1 | 15.0 |
| Lancota (check) | 14.3 | 12.5 |

[a] Based on method of Mr. A. Garzon Trula, Ministry of Agriculture, Madrid, Spain.

# WHEAT BREEDING: GRAIN YIELD VERSUS QUALITY[1/]

Calvin O. Qualset
Department of Agronomy and Range Science
University of California
Davis, California

Our goal in the development of any crop is, of course, to produce a high-yielding marketable product that has wide acceptability. Wheat epitomizes that goal and the question of high yield and good quality has been a matter of great debate over a long time in the United States and elsewhere. The title and topic of this paper was assigned to me in full knowledge that the subject is controversial. The term "versus" suggests that it may be an either-or situation. Wheat breeders have been faced with apparent negative relationships between grain yield and various "quality" characters in their breeding programs, but I suspect that most breeders would acknowledge that the goal of improving grain yield and quality is realistic. In fact, there is ample evidence that substantial genetic improvement in grain yield potential has been realized through improved crop management concomitant with improved quality. Johnson, in these proceedings, has shown that both protein content and grain yield have been improved in U.S. hard red winter wheats. As an additional example, statewide average yields in California have more than doubled in the past 15 years. The major varieties currently being grown are significantly higher in quality than the varieties of the previous 10 decades. A substantial portion of the production (principally the variety Yecora Rojo) is now widely accepted for breadmaking and the remainder (principally the variety Anza) is well accepted locally for general purpose flours. The latter variety has received criticism in the export trade, however, where the buyers often have expectations of blending wheats of outstanding breadmaking qualities with local wheats of lesser quality.

The "quality" attributes of wheat are under rather strong genetic control but are subject to environmental influences. For the breeder, the task is to produce wheats that have the genetic potential for high quality. If this potential exists in a variety, then with good crop management and favorable climatic conditions a high quality crop will be produced. For example, as will be shown later, good quality in flour for breadmaking is associated with high flour protein content and protein content is strongly influenced by available soil nitrogen. If nitrogen is limiting, grain yield and grain protein content will both be adversely affected. It is widely known that proper management of nitrogen nutrition will result in high grain yield and high quality, if the genetic potential for high quality exists in the variety. The key is "proper management of nitrogen." This depends upon temperature, amount, and distribution of rainfall, diseases, and other factors that are often outside

[1/] The USDA Western Wheat Quality Laboratory provided data for the previously unpublished results presented in this paper. Financial support was made available through the Western Regional Project W-132, Genotype-Environment Interactions Related to End-Product Uses in Small Grains, and the California Crop Improvement Association.

the realm of "proper management." Therefore, particularly in rainfed wheat production, there is risk in applying too much nitrogen fertilizer for the amount of water available to the crop. Then, if conditions are favorable for high grain yield, nitrogen may be limiting and the typical negative relationship between yield and protein is observed. In contrast, if adequate nitrogen and moisture are available, and all other conditions are favorable, grain yield and protein content can both increase as we found in a summer crop in Northern California (Puri et al, 1980).

## Defining Goals for Breeding

Breeding for yield and quality requires that we pay careful attention to the definition of quality for the targeted production region and end-use characteristics. We must also give attention to genetic and physiological considerations of grain yield. The complexity of the problem was recognized in the Western United States and a western regional research project was organized about 10 years ago which addresses all of these factors. Workers in Arizona, California, Montana, Oregon, and Washington are studying environmental conditions that affect end-use characteristics and growth characteristics such as nitrogen-use efficiency. For example, genetic control of nitrogen assimilation, reduction, and its remobilization from vegetative tissue to grain is under study so that breeders can select for better nitrogen-use characteristics that result in a high quality grain.

Defining quality such that it can be evaluated in the breeding program is complex because quality has different connotations for the grower of the crop, the miller, and the baker.

The growers must produce sound grain with the desired protein level. Many factors influence the state of grain at harvest time, such as diseases that reduce grain filling, environmental stresses (drought, freezing, or heat), and postmaturity weather damages. Breeding for high quality, therefore, includes breeding for resistance to many quality-reducing factors.

The miller expects a wheat that can be handled efficiently through the grinding process and that will produce a high yield of flour. Wheat flour can be used for many products, but water-absorbing and mixing properties are very important in the use of all milled wheat. The viscosity of the batter for pastry and gas retention for breadmaking are examples of characteristics important in the end-use evaluation of wheat flour. Finney and Yamazaki (1967) give a summary of many of the considerations in evaluating wheat quality.

Two of the many end-use tests used in judging the overall quality of wheat flour will be illustrated here. The first is the volume of a loaf of bread baked from the flour that is to be used for leavened products. The second is the diameter of cookies baked from flour that is to be used for pastry products.

## Relationship of Flour Protein to End-Use Quality

Relationships of quality parameters to protein were investigated many years ago in the various wheat-producing regions by public and private research laboratories. Figures 1 and 2 show results obtained at the USDA Western Wheat Quality Laboratory at Pullman, Washington (Barmore and Bequette, 1968). Bread

quality is strongly improved as flour protein increases, but the slopes of the lines are noticeably different for the varieties illustrated in Figure 1. In contrast, cookie quality (Figure 2) is strongly decreased as protein content increases. Again the slopes differ among varieties. The breeder, therefore, must know how a potential variety will perform at a range of protein levels because there will surely be a wide range in the prodution region. The slope of the line cannot be established without numerous tests. However, the fact that protein content is strongly related to end-use quality can be used to advantage. Evaluation trials conducted at several fertility levels can give information on yield and quality responsiveness.

Such a study was done in California some years ago which illustrates this point. Seven varieties, widely different in grain-yielding ability and quality, were studied with 0, 50, 100, 200, and 400 pounds of nitrogen per acre added. The crop was winter-grown with irrigation; the varieties were all spring wheats. The nigrogen applications resulted in only 1 to 2% change in protein content, but the variety relationships became quite clear for both bread and pastry qualities as indicated in Figure 3. For loaf volume, five of the seven varieties appear on a single regression line, but each remained in one "zone" of quality, for example Siete Cerros 66 had low loaf volume and Calidad had high loaf volume. With the exception of Sonora 64, all varieties showed increased loaf volume when the flour protein increased. With respect to pastry quality, the varieties having the best bread quality were not satisfactory, based on the cookie test. D6301 was clearly superior. Siete Cerros 66 and Pacific Triple Dwarf were not satisfactory for either bread or pastry uses and none of the wheats are obvious dual purpose types.

## Relationship of Quality to Grain Yield

The question of high quality-high yielding wheats can also be illustrated with the data from the experiment mentioned above. Loaf volume and cookie diameter were plotted against grain yield in Figure 4. The relationship of quality to yield was not generally negative. Variety Inia 66 illustrates that improved yield with good bread quality has been obtained (compared with Ramona 64, the previous standard of quality in California). The results for cookie diameter with D6301, the only satisfactory wheat for this purpose, showed slight improvement as the grain yield level increased.

Since the relationships of flour protein content to quality can be established for each variety (Figure 1, 2, 3), it is useful then to examine the relationship of protein to grain yield because this information is easily obtained and available as a marketing criterion. The righthand diagram in Figure 4 shows that protein and yield had a negative relationship for some varieties (D6301, Siete Cerros 66, Pacific Triple Dwarf, and Sonora 64) and no correlation for Ramona 64, Inia 66, and Calidad. The latter varieties, however, were the most desirable for breadmaking in this group of varieties.

What does this mean for the wheat breeder? In practice, information about quality is needed over a range of conditions that influence protein content for unknown breeding lines. Then the unknowns can be categorized for type of quality and the quality-protein, protein-yield, and quality-yield relationships can be established. The results from a single quality test can be very misleading. When a new breeding line is released as a variety, the above relationships should have been well established. These have some predictive

value so that regions of utilization for the variety can be designated. When the variety is in production, it can be marketed intelligently if two facts are known: 1) its variety identity and 2) the protein content of the grain.

## Market Classes and Quality

The way wheat is marketed is a direct concern to the breeder, especially in the context of quality control. The present U.S. market classes for wheat do not provide for end-use quality criteria to be evaluated and made part of the documentation of the product that is offered for sale. The relationship of protein content to quality is widely recognized, but it is also well known and illustrated in the Figures here that protein quality cannot be judged by measuring protein content. However, if protein content and variety identification were included as required documentation for marketing, the crop would usually be easily placed into end-use categories and the requirements of users could be met. Of course, there are a number of varieties that are similar in their end-use qualities that could be grouped as a single marketing unit. The present-day U.S. wheat market classes are not satisfactory and should be revised. The developers of wheat varieties and wheat products, the marketing agents, and users would all benefit from such a revision.

## Variety Identification and Marketing

Classification of wheats into the U.S. market classes cannot be done accurately by using kernel morphology characteristics. This is dramatically shown with varieties in California which properly are hard red spring varieties. They were arbitrarily classed as hard red winter varieties (after a few years of indecision and attempts to use the soft red winter class). These varieties have spring growth habit but are grown as a winter crop. There is potential for confusion but not necessarily so. The problem is that a "HRW" variety in the Central Valley of California is a "HRS" variety when grown in another region of the State or in another State. If the variety name was attached to the wheat throughout the marketing process, there would be no confusion.

There are methods now available that can be used to eliminate ambiguous identification in most instances. These methods utilize existing variations in wheat proteins, either in enzymes or seed storage proteins (Menke et al, 1973; Qualset and Wrigley, 1979). Protein electrophoresis has been widely studied throughout the world for wheat variety identification and could be adopted with minimal disruption of existing production and marketing practices. Wrigley and McCausland (1977) and others have developed standardized methods.

## Summary

1. Wheat breeders do not have to breed for yield or quality. There is ample evidence that quality and yield can be improved simultaneously.

2. The breeder is in a difficult situation because

   i) quality is hard to define,

   ii) it is not a measured criterion in the market place,

iii) multiple end-uses are desired by buyers,

iv) blending of varieties is done but not considered as an evaluation criterion,

v) users and quality control laboratories often demand quality performance characteristics to be in excess of that needed by the user (e.g., protein content and mixing tolerance), and

vi) buyers also require quality performance in excess of that required for direct utilization to fill export sales where high quality wheats are blended with local low quality wheats.

3. Market classes and wheat grading need to be improved to provide better description of wheat quality for the users. The addition of variety name and protein content to all wheat as it leaves the farm would improve wheat marketing immensely, but would cause some problems with storage and handling in areas where several varieties with different quality classes are grown.

4. Breeding wheat for high yield and high quality requires teamwork of breeders, agronomists, cereal technologists, economists, and users:

i) targets for quality characteristics and production areas need to be defined,

ii) seasonal and locational effects on quality need to be understood,

iii) rapid and inexpensive quality prediction tests are needed for use early in the breeding program,

iv) germplasm should be identified that has certain quality characteristics that meet or significantly exceed the presently available materials, and

v) a breeding plan should be devised that has high probability for success, is practical in scope, and is provided adequate resources for implementation.

## References


1. Barmore, M. A. and R. K. Bequette. 1968. Kernel color and shape as guides to potential flour performance in wheat marketing. Agron. J. 60:223-228.

2. Finney, K. F. and W. T. Yamazaki. 1967. Quality of hard, soft, and durum wheats. p. 471-503. In: Wheat and Wheat Improvement. K. S. Quisenberry and L. P. Reitz (eds). Amer. Soc. Agron. Monograph 13.

3. Menke, J. F., R. S. Singh, C. O. Qualset, and S. K. Jain. 1973. Protein electrophoresis aids cereal variety identification. Calif. Agri. 27(10):3-5.

4. Puri, Y. P., C. O. Qualset, C. C. Jan, and K. G. Baghott. 1980. Durum and bread-wheat response to nitrogen for yield, physical, and chemical characteristics. Phyton 39:127-145.

5. Qualset, C. O. and C. W. Wrigley. 1979. Electrophoresis and electrofocusing identify wheat varieties. Calif. Agri. 33(3):10-12.

6. Wrigley, C. W. and J. McCausland. 1977. Variety identification by laboratory methods: Instruction manual for barley, wheat, and other cereals. CSIRO Wheat Research Unit, North Ryde Austral. Tech. Publ. 4.

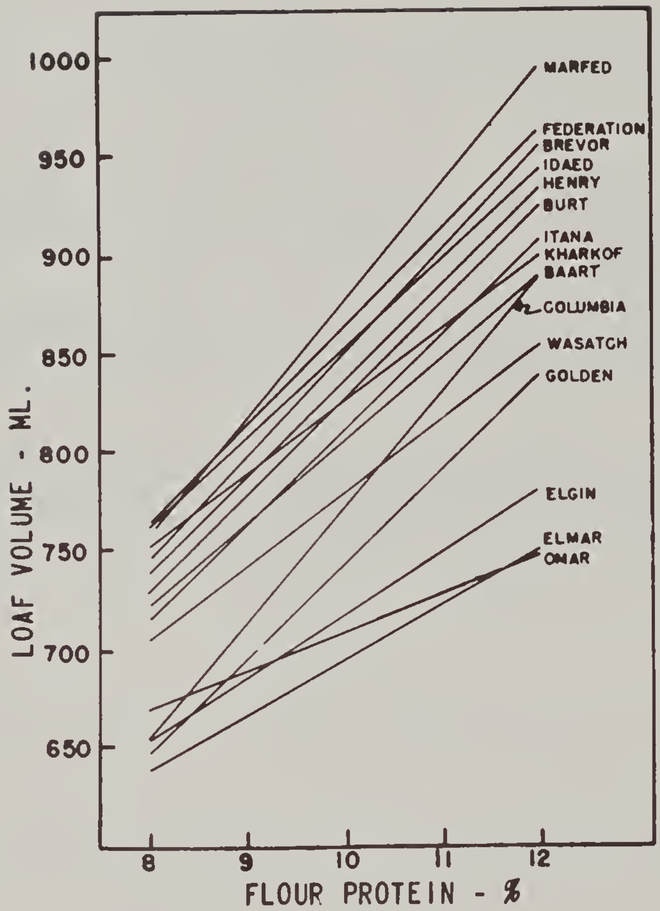


Figure 1. Relationships of bread loaf volume to flour protein content for western U.S. wheat varieties (Barmore and Bequette, 1968).

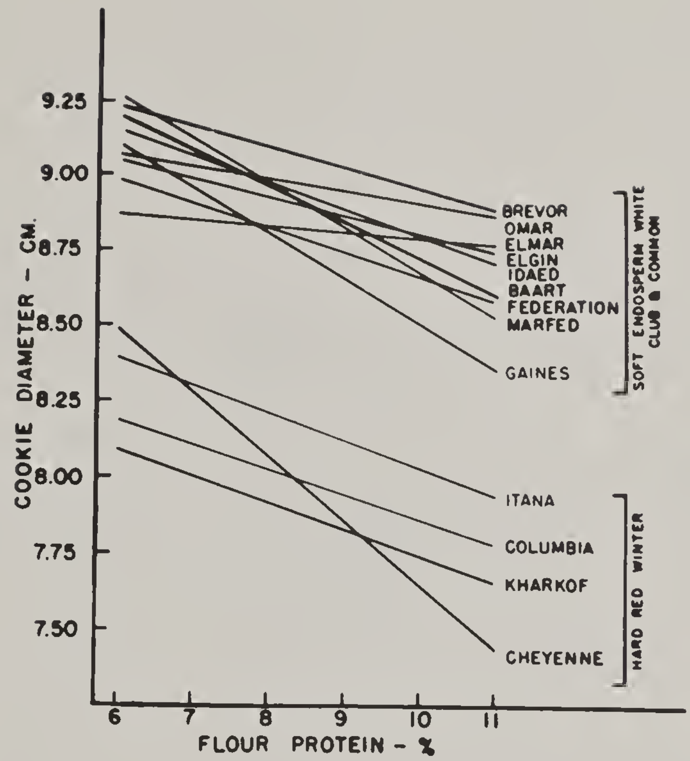


Figure 2. Relationships of cookie diameter to flour protein content in for western U.S. wheat varieties (Barmore and Bequette, 1968).

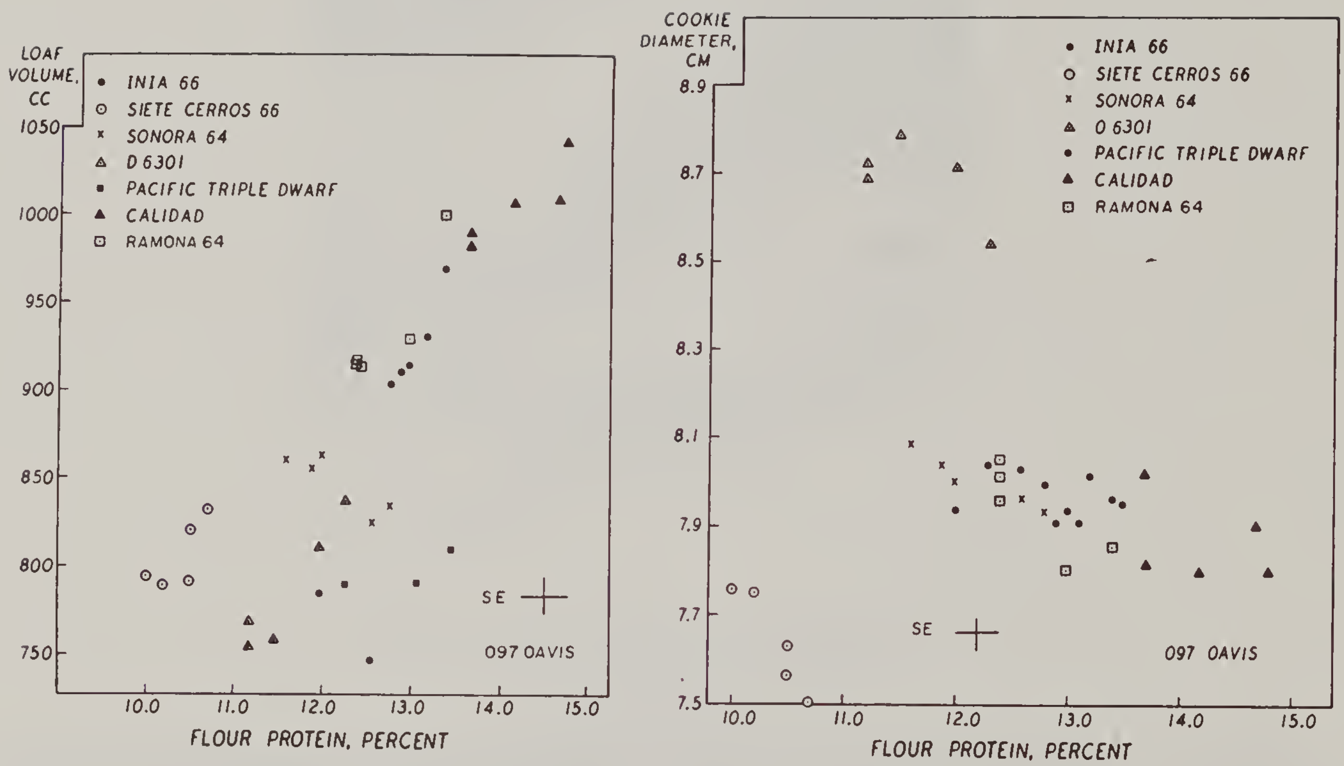


Figure 3. Relationships of loaf volume and cookie diameter for seven spring wheat varieties grown at five nitrogen levels at Davis, California.

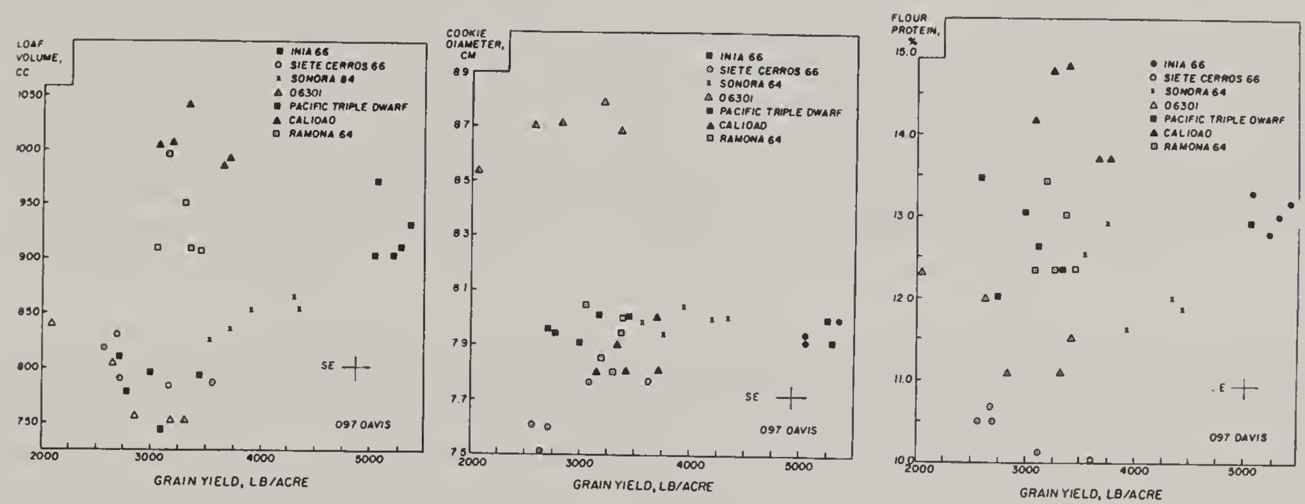


Figure 4. Relationships of loaf volume and cookie diameter to grain yield and flour protein to grain yield for seven varieties in the same experiment as described in Figure 3.

# RESEARCH TO MEET END PRODUCT USE

Kenneth A. Gilles
Administrator
Federal Grain Inspection Service
U. S. Department of Agriculture

To conduct research to meet end product use assumes that the research leader knows the various types of products potentially made from wheat. Millers, bakers, and processors use wheat and wheat products in a fashion limited only by the creativity of people's minds, cost, availability, and marketing potential. Basically, wheat research is complicated by these variations in milling, processing, and utilization.

A wheat with desirable quality characteristics for one end use may be marginally acceptable or undesirable for another. To meet these challenges, wheat research is most effectively conducted by a team of specialists working cooperatively, each with equal responsibility and authority to elucidate a phase of the research problem, together with a research director with overall responsibility. Key disciplines are agronomy, cereal chemistry, economics, entomology, plant pathology, and soil science.

In practice, unfortunately, the wheat research leader usually is an agronomist or plant breeder, frequently working alone or with limited resources, who has had little opportunity for experience in cereal chemistry, milling technology, baking, or food processing, either academic or industrial. In the United States, considerable progress has been made with this system. However, future research, while drawing on past knowledge, will require a greater appreciation for the diversity of end products and a greater knowledge of the processing techniques employed throughout the world. Moreover, a greater commitment of financial resources to expedite this research will be necessary.

# OUR CHALLENGES TO PROTECT WHEAT IN HOSTILE ENVIRONMENTS

O. A. Vogel
Agricultural Research Service
U.S. Department of Agriculture
and Washington State University
Pullman, Washington, Retired

Wheat, paradoxically, for such a widely grown crop, cannot on its own survive very long in nature. Regardless of where wheat is grown or its stage of growth, we are challenged to develop ways of protecting it from damages caused by a large array of resourceful self-perpetuating creations of nature. These crop damaging, or competing creations, or both, are so numerous and appear in such ever-varying combinations that potentially profitable yields of grain rarely are approached by commercial producers. Furthermore, the survival and prevalence of these yield reducing entities often are aided by human activities and regulations which discourage the use of the most economical methods of producing and protecting the crop. Obviously, therefore, the future potential production and availability of wheat will be dependent upon how successfully we develop and maintain relevant applied and fundamental research programs.

We have a wealth of people ready, willing, and able to conduct research but we have a dearth of people ready, willing, and able to generate required funding. Fund raising for research, therefore, is our primary challenge. How do we generate the needed funding? The easiest way is to wait until enough people experience enough losses to be self-motivated to contribute directly or to persuade political actions that result in State or Federal appropriations. State and Federal appropriations, however, have a history of inopportune vacillations which discourage the undertaking of long-term in-depth research, and greatly reduce badly needed team work among research units.

Fortunately in recent years at Washington State University, the Washington Wheat Commission has provided critically needed supplemental operating funds plus other funds to support additional selective research projects. This organization has progressively increased its influence, principally because of its several-fold objectives, which include promoting and supporting badly needed production-oriented research, market development, and public relations.

Although the wheat research funding obtained by WSU from the wheat commission and other private sources comprised only approximately one-fifth, compared with four-fifths from State and Federal appropriations, the benefits derived therefrom have been disproportionately greater. This difference resulted from the positive influence the delegated representatives of these organizations had on the priorities of funding and evaluations of ongoing research efforts. The full potential of grower input into promoting funding has not been utilized, nor that of various private entities. We have been very lax in promoting endowments, and we have been relatively ineffective in competing with other segments of society for fundings from existing foundations.

Naturally we have relied upon the growers and relevant organizations for motivations in promoting State and Federal fundings, which, for example, at WSU, has been roughly 60% and 20%, respectively, of the funding chargeable to wheat research. These fundings essentially represent public contributions. Our challenge is to help find ways to continue and encourage more of this public input. Actually the public derives the benefits from this important food crop, while creating many of the obstacles to the profitability of producing, handling, and processing wheat. Therefore it is a moral obligation for the public to provide the greatest portion of the research costs. If we are unable to help convince relevant public officials that additional research not only is needed, but pays off, we must therefore wait until the lack of it results in damages sufficiently heavy to motivate public support. Federal appropriations have a special role in the enhancement of progressive developments of interstate and international research programs. The present production levels have resulted in large part from the teamwork among relevant workers created from Federal appropriations. Important ingredients in the success of the teamwork have been the highly effective interchanges of information and materials, and a healthy mixture of cooperation and competition among the workers.

Unfortuantely two recent developments tend to have a negative influence on the potential effectiveness of teamwork efforts. These are the dwindling of appropriations for production-oriented research and the plant patent laws which tend to decrease the interchange of information and materials. These developments also have a negative influence on the stature and research and teaching capabilities of the land-grant institutions which are supposed to aid agriculture through research and teaching. Obviously the subsequently weakened institution becomes less competitive in attracting needed personnel and research funding.

The patent laws do favor the development and survival of private breeding organizations. However, like the institutionally funded researcher who is burdened by "publish or perish," the private breeder has to produce or perish. Herein is a challenge for the development of a plan whereby both join in teamwork efforts beneficial not only to each other but for progressive improvement of local, regional, and national wheat production.

Endowments administered by foundations have been important sources of funding for wheat research, the most notable of which is the Rockefeller Foundation. The amounts contributed to production-oriented wheat research generally are relatively small compared with the totals contributed to their other prescribed objectives. Endowments established for the exclusive funding of wheat research can become an important and relatively consistent source of support, especially for long-term in-depth research. To generate interest in and willingness to contribute the large sums of money required to establish such an endowment is not an easy task. Therein is a challenge to combine all of one's talents for a very difficult but worthy course of action.

There is no prescribed course of action for successfully promoting an endowment for supporting wheat research. I, for many years have tried to figure out how to get one established in our State. It took a combination of three situations for me to develop enough courage to attempt to initiate a course of action. These situations were: 1) results from Dr. Cook's soil fumigation research which revealed potentials for significantly increased yields of grain; 2) unexplained causes for poor seedling vigor in late fall-planted wheat in annual cropping especially managed for controlling soil erosion; and 3) the willingness of my wife to contribute part of our savings to match other contributions during the first six months after we issued the challenge for grower contributions to establish the Vogel Wheat Research Fund at Washington State University. The challenge was announced on July 5, 1980.

As a result of our challenge the total contributions to date from over 900 contributors have exceeded $236,000, plus several substantial unpublicized deferred gifts. The interest earned therefrom has been sufficient to initiate three separate research projects. The success of this venture was due principally to the challenges made by various organizations and individual contributors to match their contributions. The great bulk of the contributions resulted from the challenges issued by members of the Washington Association of Wheat Growers. Also contributing to the success was the favorable coverage by the news media.

Noteworthy results from one of the research projects reveal the need for genetic engineering of bacteria involved in the early stages of residue decomposition. This research would aid in identifying the sources of injury to wheat roots and also would promote production of sufficient quantities of the antagonistic or injurious materials to facilitate the breeding for resistance in wheat and the discovery of new methods for controlling or managing antagonistic microorganisms. The Federal government, according to a 1981 report by the National Science Foundation, had an annual budget of 150 million dollars for genetic engineering research. Why not divert a portion of that amount to genetic engineering of microbiological organisms adversely affecting the production capabilities of wheat?

Whenever or however any of us proceed in trying to find new or more effective ways for protecting wheat in hostile environments we need another important ingredient, namely open-minded personal communications among all concerned. The present undertaking by the National Association of Wheat Growers Foundation is an important step in fostering this ingredient. For this effort the Foundation is to be commended.

# TILLAGE, CONSERVATION, AND CULTURAL PRACTICES

Chairman - Jim Billington, NAWG, Altus, OK
Secretary - R. I. Papendick, ARS and Washington State University
Panel Members:

- R. E. Allan, ARS and Washington State University
- H. F. Harrison, Coker's Pedigreed Seed Company, Hartsville, SC
- R. R. Johnson, Deere & Company, Olin, IL
- J. F. Power, ARS & University of Nebraska
- J. L. Sheffels, Washington Wheat Commission, Wilbur, WA
- D. C. Thill, University of Idaho
- B. B. Tucker, Oklahoma State University

Two wheat growers on the panel, Jim Billington, Chairman, and Jerry Sheffels, reviewed some typical problems confronting farmers in their respective areas. These included low rainfall and its highly variable distribution, wind and water erosion, weeds, insects, diseases, available nitrogen, and poor seedling plant vigor. Both of these growers (and many others) have been trying conservation tillage practices in the form of limited tillage or no tillage but with varying degrees of success. Their major problems involve weed control, operation of planting equipment, poor stands, and poor seedling growth. Mr. Sheffels indicated that he must burn the crop residue to grow wheat after wheat in order to produce wheat economically. He can get by without burning when producing continuous barley. Seeding in stubble is a major problem. The commonly used double disc drill does not operate well in wet stubble. Poor stands commonly result from planting with chisel-type equipment. Mr. Sheffels feels that he can control erosion with conservation tillage, even in annual cropping, but major problems still exist with stand establishment and yields.

Several panel members indicated that considerable research information is becoming available on conservation tillage systems, but many unknowns remain and act as barriers to implementation of practices by farmers. For example, no-till fallow can save several inches of water in a single season. Several years of no-till can build up organic matter in surface layers of the soil. No-till can result in greater problems with pests (insects, diseases, nematodes, weeds) or with stand establishment whereby the additional water saved may not bring about increased yields. Water conservation benefits are noted most in dry years. Limited or no-till results in soil that is wetter, colder, more compact, and less aerated. Deteriorating surface residue generally ties up some soil nitrogen so that higher nitrogen fertilizer rates are needed for high crop production, at least for the first few years until an equilibrium is reached.

The panel members concluded that future research should be expanded on key problems associated with grower implementation of conservation tillage systems. Education and extension of research results to farmers is an important need. Major thrust areas should include:

1. Planting equipment. A major barrier to progress is lack of reliable and economic planting equipment. Engineers need

agronomic input in their quest for design criteria which will help them develop ideal row spacing, planting rate and depth, and cropping systems.

2. Pest Control. Practices must be developed to control weeds, insects, and diseases in conservation tillage systems. Weeds are the principal problem associated with reduced tillage and with no tillage. Rotations must be considered that are flexible within tillage and cropping systems and that can be used in conjunction with chemicals for pest control. More effort must be directed toward control of winter annuals and broadleaf perennial weeds, as well as to residue inhabiting insects and diseases associated with heavy surface residue.

3. Soil microbiology. Research is needed on the effect of soil microorganisms on roots of young wheat plants growing in the presence of crop residues in annual cropping systems. There is evidence that certain microorganisms can proliferate under these conditions and become extremely inhibitory to root growth. Research is needed to identify the microorganisms, determine environmental conditions that favor their growth, and methods of control.

4. Soil fertility. Considerable research needs to be done and fertilizer requirements and plant response under conservation tillage systems. Soil tests and calibration data are needed for secondary and micronutrient requirements.

5. Straw management. This is a major problem in many conservation tillage systems. Work is needed on ways to manage residues to reduce phytotoxic effects, on pesticides application techniques in the presence of surface residues, and on ways to handle straw to improve seedling vigor. The slot mulch concept and the paraplow discussed by Dr. Papendick should be considered as possible approaches to the problem.

6. Plant stress physiology. Basic research is needed on physiological requirements to obtain good stands of vigorous plants and on how to keep such plants healthy and growing well under a variety of tillage and cropping systems. Wheats that can develop under cooler and wetter conditions characteristic of conservation tillage systems are needed.

7. Mechanical conservation practices. Previously developed procedures such as terrace building, grassed waterways, and contouring were designed with smaller equipment in mind than is used today. Mechanical erosion control practices are now largely ineffective and must be redesigned for larger field equipment.

There was considerable discussion concerning research approaches that would most likely lead to achievement of the goals and objectives involved with conservation tillage research. It was clearly pointed out that problems in one production region may be quite different from those in another region. There is no single universal solution. Appointment of a task force was suggested as a means to identify and delineate major obstacles to successful conservation tillage.

The STEEP (Solution to Environmental and Economic Problems) program currently underway in the Pacific Northwest was discussed as a possible model for regional research on conservation tillage. The STEEP program is a multi-state-federal research approach by scientists in a number of disciplines to solve a single problem - that of serious soil erosion. Such research must be conducted in place because much of the technology involved is site specific. There was general agreement that STEEP could be accepted as a model, particularly to encourage researchers to reassess priorities, focus on problems, and move research into areas of high priority without regard to specific disciplines. STEEP also has been effective in encouraging team research and conservation of resources, the latter being particularly important in these times of limited budget support.

## GERMPLASM AND ITS IMPORTANCE FOR THE FUTURE AND TOLERANCE TO HEAT, DROUGHT, AND COLD

Chairman - W. E. Kronstad, Oregon State University
Secretary - D. H. Smith, Jr., ARS, Beltsville Agricultural Research Center
Panel Members:
J. R. Erickson, HybriTech Seed International, Wichita, KS
Quentin Jones, ARS, Beltsville Agricultural Research Center
Glenn Moore, NAWG Foundation and Montana Wheat Research and Marketing Committee, Willard, MT
E. L. Smith, Oklahoma State University

Of all the environmental stresses that wheat is subjected to, limited moisture is one of the most important on a world-wide basis. Only a few research programs stress tolerance to heat and drought. Existing programs are located at CIMMYT, Oklahoma State University, University of California, Colorado State University, and Oregon State University. Oklahoma scientists are using wheat varieties and lines from the Steppes of Russia, California stresses Agropyron and other species as sources of tolerance. Colorado is evaluating genetic stocks for potential under stress environments of 10 to 12 inches of rainfall under no-tillage regimes. Oregon people are investigating the association of chloride and the moisture status of the wheat plant.

With the ever increasing cost of irrigation, greater acreages of dryland wheat production can be anticipated.

Research in this area is inadequate, not only for existing needs but particularly for the future. Drought and heat tolerance needs to be defined in terms of local adaptation. Appropriate techniques for evaluation of germplasm for drought and heat tolerance must be developed through the interdisciplinary team approach involving plant breeders, physiologists, agronomists, biochemists, and others. Evaluation of segregating populations on an individual plant basis would be of real significance. Special program funds like those supporting STEEP should be sought for drought and heat tolerance research. This would be an effective means of bringing scientists together from various disciplines, different states, and other agencies to solve a specific problem. New bio-technology techniques may be important.

Wheat germplasm needs to be systematically evaluated under different environments. Information collected will be made available through the National Plant Germplasm System (NPGS). Inter-generic crosses of wheat x rye, wheat x Agropyron, wheat x Elymus (and other species) need to be made and evaluated for possible tolerance to drought and heat. The National Small Grains Collection should be enriched with additional collections made from domestic and international wheat improvement programs, and from genotypes which have been grown for generations under stress conditions in all parts of the world.

Current research efforts are certainly inadequate in view of the magnitude of drought and heat limitations on wheat production. The Panel recommended that the NPGS coordinate research through existing staff in the Plant Genetics and

Germplasm Institute at the Beltsville Agricultural Research Center, Beltsville, Maryland.

Another very important area of wheat research is that of cold tolerance, more commonly known as winterhardiness. It is another major limiting factor for wheat production in the U.S. Genetic stocks have been identified with adequate levels of winterhardiness for some areas; but if varieties developed from those stocks become popular, they inevitably are grown farther north than they should be and losses from winter killing are sustained. Cold tolerance is not a simple biological phenomenon; it is a complex of biological phenomena. To be researched effectively, components must be studied. Adequate screening techniques to identify desirable genotypes are not available. High levels of winterhardiness seem to be negatively associated with high yield. Limited attempts have been made with intergeneric crosses to obtain levels of hardiness in wheat equal to rye. Success has not been achieved. For the future, we need to define what type of winterhardiness (components of the complex) is most important for a specific geographic area. We must have better understanding of the morphological, physiological, and genetic factors involved. A particular need is that of an effective screening technique to identify useful genotypes in segregating populations. The National Small Grains Collection should be enriched by the infusion of improved selections and varieties with superior winterhardiness. There is a real need for fundamental information on the relationship of root development, crown depth, and other morphological, physiological, and genetic factors on winterhardiness.

Public and private industry research efforts are directed toward the common goal of increasing productivity and profit for the farmer as well as benefiting the consumer. These efforts should compliment one another. Competition within and between the public and private sectors should be healthy and beneficial to all concerned. Germplasm evaluation and enhancement is a vital and integrated part of all wheat improvement programs. Both the public and private sectors should be involved. The role of the universities requires strong public breeding programs in order to insure continued training of qualified plant breeders and other scientists. We need closer participation of public and private research personnel in securing funding, sharing of information, and training new scientists.

## DISEASE AND INSECT CONTROL THROUGH BREEDING

Chairman - J. H. Hatchett, ARS and Kansas State University
Secretary - K. B. Porter, Texas A&M University
Panel Members:
- Walter Adams - Oklahoma Wheat Commission, Sharon, OK
- Rick Baird - Minnesota Association of Wheat Growers, Red Lake Falls, MN
- C. M. Brown - University of Illinois
- R. H. Busch - ARS & University of Minnesota
- R. J. Metzger - ARS & Oregon State University
- R. W. Romig - Northrup King Company, Minneapolis, MN
- Howard Ward - Kansas Association of Wheat Growers, St. John, KS

Current research in breeding wheat for disease and insect resistance represents a sizable portion of the total breeding objective. Significant accomplishments have been made in reducing the susceptibility of wheat varieties to certain pests as exemplified by resistance to certain races of rusts and to the hessian fly. Nevertheless, current breeding efforts are no more than adequate compared to those needed to defend the crop against new races of rust and other diseases and to frequent changes in insect biotypes. Capabilities of current research programs are not sufficient to permit an intensive search for new and better sources of resistance nor the development of more adequate germplasm for resistance to the numerous diseases and insects attacking wheat. Current research capabilities will not permit the conduct of sufficient basic research on pest-host-environmental relationship that could contribute to a more positive approach in breeding for stable resistance.

Emphasis on new research should reflect new needs associated with changing cultural practices. The increasing use of minimum or conservation tillage has indicated the increasing importance of various diseases and insects which previously were at least partially controlled by conventional tillage. Increasing use of short wheats has tended to change canopy relationships with leaf spotting fungi. Examples of diseases identified as highly important are Septoria tritici, Septoria nodorum, and tan spot, along with various root attacking fungi. Increased insect problems would include hessian fly, wheat curl mites, and aphids and their role as vectors of viruses. Older identified problems should not be deemphasized, since continued effort is required against a constantly changing pest.

Rather than reducing or discontinuing areas of research for pest resistance, each breeding program should be periodically reviewed and resources reallocated as indicated by current and foreseeable future needs.

Further exploitation of sources of resistance is necessary for continued progress. Exotic germplasm sources need enhancement (preliminary breeding) for convenient use in breeding programs. Pests vary in importance by region and require regional assessment for priority. Some examples (although regional in nature) are:

1. Greenbugs, other aphids, and the hessian fly
2. Wheat streak mosiac, barley yellow dwarf, and other viruses
3. Foliage and spike fungi
4. Root and crown rot organisms

Continuation and possible expansion of the various regional uniform pest resistance evaluation and performance nurseries is of utmost importance. This allows wide area assessment of resistance or tolerance to various pests or pest related stresses.

Although private industry can make valuable contributions, there is little evidence at this time that they will develop the needed coordinated effort required for continued improvement in pest resistance, primarily because of low immediate economic return.

## CHEMICAL AND BIOLOGICAL CONTROL OF WEEDS, DISEASES, AND INSECTS

Chairman - Steve Keil, Chairman of NAWG Farm Chemicals Committee, Conrad, MT
Secretary - R. J. Cook, ARS & Washington State University
Panel Members:
- J. F. Carr, South Dakota Wheat Commission, Pierre, SD
- Ray Davis, Nebraska Wheat Development, Utilization, and Marketing Board, Potter, NE
- J. D. Nalewaja, North Dakota State University
- Tom Peeper, Oklahoma State University
- J. W. Searcy, DuPont Company, Wilmington, DE
- John Wollan, Mobay Chemical Corporation, Japa, MD

The agricultural industry is undergoing some major changes in farming practices. The two most significant changes are: (1) the shift from moldboard plowing to stubble mulch tillage (also known as conservation tillage) and (2) shift to shorter or no crop rotation. The older practices have long provided a significant measure of natural biological control of weeds, disease organisms, and insect pests that only now can be fully appreciated - since the controls are no longer operative. The result is an array of root and leaf diseases, insect pests, and new weed problems heretofore unknown to most farmers in business today.

Mr. Ray Davis of Western Nebraska reported that he switched from the moldboard plow to stubble mulching when the oil embargo was imposed. This shift made tillage cheaper, made it possible for him to use larger equipment, and it gave better control of soil erosion. However, for the first time, it became necessary to fertilize and also to apply herbicides -- treatments and costs not necessary when the plow was used -- simply to maintain his yield.

The problems on Mr. Davis' farm were echoed by other farmers in the audience. They asked researchers to find and develop chemical and biological control methods that will control pests to the degree that the farmers will not have to resort to longer crop rotations or return to the moldboard plow.

Growers also made clear in this workshop that the cost of pesticide use must be reduced.

Research needs identified:

1. Better information on crop losses - we need actual figures to quantify losses. Industry (chemical companies in particular) requested this to help them focus on the important problems. The cost of development of a new chemical is now $20-30 million.

2. Better and more information on the biology and ecology of the insect, weed, and disease organisms. This should include studies to determine <u>why</u> we have the pest problems that now exist? Why were they not present with the moldboard plow system? Public support is needed for this kind of research.

3. Cost reduction with pesticide use and increase in efficiency of pesticides. Methods are needed that will permit farmers to apply as little as necessary, to prevent losses to the atmosphere, and to work more with mixtures of pesticides.

4. Biological control to supplement or replace chemical controls. We need somehow to do the job long done naturally by crop rotation and the moldboard plow. Biological controls can involve proprietary products so that a market and profit can be obtained by industry. Such biological controls can be developed by industry in cooperation with the public research sector. Other biological controls can be accomplished through changes in cultural practices to favor natural enemies and beneficial organisms.

Complexity of the pest problems cannot be overestimated. Moreover, each aspect of the problem is tied to every other aspect and no one problem can be solved without consideration of the others. For example, the weed problem in reduced tillage systems exists, in large part, because the wheat plants are less competitive. The wheat plants labor under stress from root and leaf diseases. If those maladies are controlled, part of the weed problem will also be lessened. An approach needed is that of Integrated Pest Management (IPM) research whereby an entire ecosystem is considered. Ways must be found to stablize production through better chemical and biological control of pests that farmers can afford.

## HYBRID WHEAT AND PROGRESS IN USE OF PLANT GROWTH REGULATORS

Chairman - Anson R. Cooke, Union Carbide, Research Triangle Park, NC
Secretary - Charles Hayward, Pioneer Hi-Bred International, Inc., Hutchinson, KS
Panel Members:
- W. O. Johnson, Rohm & Haas, Philadelphia, PA
- K. A. Lucken, North Dakota State University
- B. J. Roberts, Cargill, Inc., Fort Collins, CO
- Ed Ross, Minnesota Wheat Research and Promotion Council, Fisher, MN
- J. W. Schmidt, University of Nebraska
- T. S. Smith, Union Carbide, Greensboro, NC
- Frank Tubbs, Oregon Wheat Growers League, Adams, OR

J. W. Schmidt showed slides on the cytogenetics of corn, sorghum, barley, and wheat. Wheat is the only hexaploid (has three similar sets of chromosomes). The other crops have only one set of chromosomes each. Theoretically, one would expect less heterosis (hybrid vigor) to be expressed by hybrid wheat than by hybrid corn, sorghum, or barley.

Wayne Johnson indicated that about 1,000 wheat hybrids were produced by cooperative programs in 1982, through use of the Rohm & Haas pollen suppressant procedure known as Hybrex. Hybrid seed produced tended to be slightly smaller and frequently shriveled compared to conventional wheat seed. Union Carbide and Shell representatives stated that shriveling had not been detected in hybrid seed produced through use of their pollen suppressant compounds. Cargill and Pioneer breeders indicated that their hybrid seed (produced through use of cytoplasmic male sterility and genetic fertility restoration) was larger than conventional wheat seed. Actual field performance of hybrids was similar, regardless of methods used to produce hybrid seed.

Milling and baking performance poses no problem in hybrids. Quality is entirely dependent upon parental characteristics and the environment which hybrid plants are subjected to. There is no reason to believe that quality of hybrids is any different from that of conventional varieties.

The primary concern expressed in the workshop over hybrid wheat versus varieties was economics of seed production.

There is a distinct need for basic research on genetics and physiology of male sterility and fertility. The possibility of apomixis in wheat, and other species, should be investigated. Such research should be conducted by public agencies.

Most research and development of plant growth regulators is done by private industry. Testing is conducted by both private and public agencies. Current use of growth regulators on wheat is for the control of lodging. A question was posed on the legitimacy of a plant breeder introducing a variety with growth regulator requirements for prevention of lodging. Several expressed the opinion that growth regulators should be available as a management option for the grower. Timing and rates of application of Ethephon (CERONE) for maximum

benefit (prevention of lodging) were discussed. There tends to be a 2-3 day delay in heading but treated plants dry down sooner than untreated plants. Union Carbide representatives recommended that the growth regulator be used only under high production conditions.

Future research needs include studies on the effect of day length and other genotype differences on expression of growth regulators. More research is required to learn the basic mechanisms involved when plant growth regulators are applied - which enzymes, hormones, or biochemical systems of the plant are involved. Such research can be done by both private industry and public agencies.

# IMPROVEMENT OF WHEAT QUALITY

Chairman - Lyle Smith, Idaho Wheat Commission, Felt, ID
Secretary - V. A. Johnson, ARS & University of Nebraska
Panel Members:
- J. E. Bernardin, ARS, Western Regional Research Center, Albany, CA
- K. A. Gilles, Administrator, Federal Grain Inspection Service, USDA, Washington, DC
- V. V. Goodfellow, President, Crop Quality Council, Minneapolis, MN
- Mike Kubicek, Oklahoma Wheat Commission, Oklahoma City, OK
- R. L. Morris, Continental Baking Company, Rye, NY
- C. O. Qualset, University of California, Davis, CA

Wheat quality can be defined only in terms of end use. R. L. Morris suggested that evaluation criteria now used are out of date for high speed bakery operations. Research is needed to develop more useful and appropriate tests for measurement of acceptability of wheat for modern baking. Such research must be done in the public sector; the private sector is not likely to undertake it; and if it did so, the information would be proprietory and not generally available to the entire industry.

Particular production climates indigenous to various areas of the United Sates should be better exploited for production of wheats with certain desired combinations of traits. Wheats produced in the various wheat regions or areas should be targeted for specific markets. The need for team research to probe more deeply the chemical and physical properties of wheat grain that interact to produce end use quality traits was emphasized.

The attitude of producers relative to wheat quality and its importance domestically and for international trade must be reckoned with. At present the groups most concerned with quality of U.S. wheat are (1) millers and bakers in importing countries, (2) elevators in importing countries, (3) U.S. millers and bakers, (4) U.S. wheat exporters, and (5) buyers and sellers of U.S. wheat. More attention needs to be given to buyer expectations.

Continued strong public sector research on wheat quality is necessary. Quality criteria for domestic and foreign use are often different. Producers generally are not adequately compensated for high quality. The importance of defining quality and methodology to assess quality quickly and efficiently for use by breeders was stressed.

The importance of regional wheat nurseries and regional wheat quality laboratories to the continued quality improvement of U.S. wheat varieties was pointed out. These activities are absolutely necessary to maintain the high quality of U.S. wheats. Research on quality remains an appropriate activity for ARS. Support for some of this type of "service" research within ARS appears to be in jeopardy.

Research on wheat protein and its genetic manipulation should be pursued. New genes affecting protein in wild species should be researched for possible exploitation. Our understanding of wheat quality and crop management relationship is inadequate and should be pursued.

The U.S. wheat marketing system was identified as contributing to problems of wheat quality. Very little U.S. wheat moves through market channel on an "identity preserved" basis. This results in an averaging of quality via variety mixing. A concern and continuing frustration of U.S. wheat breeders is the failure of the milling and baking industries to define precisely what kind of quality they want. Public-private consortia may be needed and useful to correct this. Wheat exports on an "identity preserved" basis may be feasible via "container" movement of wheat shipments.

## Tillage, Conservation, and Cultural Practices

There is promise that erosion can be controlled with conservation tillage but there are still problems with stand establishment, yields, and profitability.

Continuing research is needed on planting equipment, pest control, soil microbiology, soil fertility, straw management, and the like.

The STEEP program was considered favorably as a model for other site specific problems where multidisciplinary, multiagency approaches are indicated.

## Germplasm and Its Importance for the Future and Tolerance to Heat, Drought, and Cold

Limited moisture is one of the most important production constraints worldwide.

Germplasm now used in search for drought, heat, and cold tolerance includes: varieties from steppes of Russia, Agropyron, Elymus, and other related species, and various genetic stocks.

Association of chloride and the moisture status of the wheat plant is being studied.

Increased cost of irrigation is going to result in greater acreages of dryland wheat in the future.

The critical need is good techniques for evaluation of breeding lines for drought, heat, cold. We need definitive screening procedures.

Interdisciplinary team approach is mandated to understand physiology of the wheat plant in relation to these stresses.

Germplasm needs to be systematically evaluated under many different environments by both public agencies and industry.

## Disease and Insect Resistance Through Breeding

Current research, while representing a sizable portion of total breeding objectives, is sufficient only to defend the wheat crop against new races of rusts and other diseases and the frequent changes in insect biotypes.

Additional resources are needed (1) to support basic research on pest-host-environmental relationships and (2) to permit researchers to address adequately the new needs associated with changing cultural practices.

## Hybrid Wheat

Cytoplasmic and chemical approaches to the production of wheat hybrids are available.

Major concern of the workshop was with economics of hybrid seed production and use.

Additional research on the genetics and physiology of male sterility and fertility and apomixis in wheat were recommended to public research agencies.

## Plant Growth Regulators

Group discussed results obtained in tests of compounds developed by private industry to reduce lodging.

There was agreement that additional research is desirable by both public and private groups to provide a better understanding of the enzymes, hormones, or other components of the biochemical systems involved.

Use of compounds to decrease lodging will likely be limited to high production wheat growing areas.

## Chemical and Biological Control of Weeds, Diseases, and Insects

Two significant changes are underway in farming practices: (1) shift from moldbroad plowing to stubble mulch or conservation tillage and (2) shift to shorter or no crop rotation.

These shifts have been accompanied by an array of root and leaf diseases, insect pests, and new weed problems not previously encountered. Economical controls are badly needed but not presently available.

Additional research is needed after the IPM model which involves a wholistic, ecosystem approach among several disciplines and functions with improved communication among all concerned.

## Wheat Quality

Because wheat is a major food crop, its nutritional value as well as its suitability for processing into numerous end-use food products are important. Genetic research to improve nutritional quality, including identification and transfer of useful genes from exotic species, should be pursued. Precise quality needs of the wheat processing industry need to be better defined to allow the development of definitive tests to evaluate the suitability of new wheats for modern bakery processing. Research to more adequately understand the complex chemical and physical properties of wheat grain that contribute to processing quality should be accelerated. Continued leadership of ARS in regional evaluation of wheat performance and quality was strongly recommended.

Capstone statements, such as this, reported as a highlight of the Conference by several representatives:

> "This was an outstanding meeting in my opinion because it is a first for representatives of Federal and State research, industry, wheat commissions, and growers to get together and exchange information, become better acquainted, and begin to make plans for the future. We believe this should be the first of a series of continuing conferences."

ADDRESS BY SENATOR MARK ANDREWS
Republican, North Dakota
Member Committee on Appropriations
Sub-Committee on Agriculture and Related Agencies

I am truly honored to be invited to speak at this very first National Wheat Research Conference. As a wheat farmer myself, and a Senator from North Dakota--the State that topped the nation last year in wheat production--I probably would have tried to sneak in the back door to mingle and learn a few things even if you hadn't invited me. I certainly wouldn't have wanted to miss the first conference held specifically to bring together wheat growers and researchers to exchange valuable information on wheat research.

And, no one knows better than you the importance of agricultural research. American Agriculture is the most efficient and productive in the world.

About 12,000 years ago, humans discovered agriculture and learned how to domesticate animals. World population then is estimated to have been approximately 15 million. It doubled four times to arrive at a total of 250 million by the time of Christ. At the current world rate of population growth, population will double again in the next 33 years, reaching eight billion people by 2015. This means that in the next 33 years, world food and fiber production must be increased more than it has increased in the 12,000-year period from the discovery of agriculture.

This is a tremendous undertaking and of vital importance to the future of civilization. Failure will plunge the world into economic, social, and political chaos. The question is, can the production of food and fiber be doubled in the next 33 years? It can provided we give high enough priority and continuing support to agriculture and agricultural research.

The most dramatic of America's achievements has been its agriculture. If you look back to the founding of this country something like 80 to 90 percent of the people were on farms. Today fewer than 4 percent of the American people are on farms. This is really the miracle of America. In 1776 the American farmer produced only enough for himself and two others. Today one farmer grows enough for himself and about 77 others.

Although 50 percent of the total world population is engaged in agriculture and animal husbandry, the percentage varies greatly from country to country. Contrast the success of America's farmers with the fact that in countries such as Bangladesh, India, and Pakistan 70 to 75 percent of the population is in agriculture. World food production needs cannot be coped with unless crop yields are greatly increased. This being the case, far greater emphasis must be given to improving the agricultural output in the developing nations that have been until recently largely untouched by modern agricultural technology.

It is quite one thing to sit over here, both as a farmer and as a Senator, and ponder our problems--prices, production, operating costs, and all the rest--and quite another to listen to people from all over the world who tell you that a loaf of bread or a bowl of rice is the stark difference between life and death.

Our national investment in agriculture has over the years given American consumers the best food bargain in the world. Our farmers were encouraged to increase the quality and quantity of their food yields because of our government's commitment to these goals. If government fails to follow through on its responsibility, you can be sure that consumers will be faced with higher prices at the marketplace.

During this fiscal year, the U.S. Department of Agriculture will spend nearly $14 billion on domestic food programs with only about $5 1/2 billion going for our agricultural programs, farm research, and conservation.

This is what has been happening. In the last ten years, funding for agricultural research has barely kept pace with inflation, and there is some evidence that it has lost ground. I don't have to tell you how badly this research is needed to increase crop yields and to produce disease resistant crops. And, every American has a stake in this research. Between 1950 and 1971, U.S. farm ouput increased 50 percent, while consumer prices remained relatively stable. If the same farming methods had been used in 1971 as in 1950, an equivalent abundance of food and other products coming from the farm would have cost two to three times more than they did.

The practices and technologies that will be available to sustain and enhance agricultural productivity for the remainder of the century are being developed, studied, and evaluated in research laboratories. Primary emphasis is being placed on basic and applied research directed toward improvement of germplasm and varieties of wheat so that new breeding material and varieties will produce more grain per acre, will have more effective protection from diseases and insects, will be better able to withstand bad weather, and will produce high quality and more nutritious grain for food and feed.

All farmers have been plagued through the years by various types of diseases, blights, and fungi that reduce yields or even totally destroy fields. Without some other strain of the seed to plant the following year, farmers would be out of business.

We all remember the southern corn leaf blight which destroyed half the corn crop in many States and created an economic loss not only for the farmer but consumers who paid higher prices for grain products and meat. Fortunately, researchers had other strains of corn available so the following year corn could be planted that was resistant to leaf blight.

As a member of the Agriculture Appropriations Subcommittee in the House I questioned scientists in March of 1971 about developing strains that would prevent an entire crop from being wiped out by some new disease. They assured

me that through increasing use of different germplasm, new varieties were being developed that would have different genetic backgrounds and thus various resistances to disease.

The near tragedy we suffered from having over half of our corn destroyed points out the need for having different strains available for our farmers. The germplasm banks we are now developing are the direct result of our efforts that long ago.

This 10-year span is an indication of the time required to research and develop new grain varieties. We were fortunate we started in Congress that long ago to recognize the need to control many diseases. Furthermore, it emphasizes the need to continue this research without interruption. For that reason my Agriculture Appropriations Subcommittee has increased by a third funds for obtaining and developing germplasm so vital to a healthy agriculture.

Now to the subject you are especially interested in--wheat research. As you know there are four Wheat Quality Laboratories, and as a North Dakotan, I am proud to say that the one at North Dakota State Univeristy in Fargo has contributed greatly to this important research. Their work is a credit to the cooperation between ARS, the Experiment Station and the University. The Experiment Station at North Dakota State University has been responsible for releasing over 36 varieties of wheat. Release of a new durum variety, and the release of a new Hard Red Winter wheat variety are pending final decision. Announcements for these two new varieties will very likely be made during the winter of 1982-83.

Hard Red Spring Wheat is the most important agricultural commodity produced in North Dakota. The NDSU-developed, new, superior varieties of wheat are estimated to have added $68 million new wealth in 1978-1979 alone. Newer superior experimental lines are being developed every year, which will add still higher percentages of income improvement due to higher yielding ability.

These improvements have been made while maintaining the traditional high quality and high protein content of the hard red spring wheats produced in North Dakota. The benefit/cost ratio of NDSU research on hard red spring wheat is estimated at 100 to 1 for North Dakota benefits alone. That means for every dollar we spent on research we received a return of $100.

The same benefits from durum wheat research were $49 million, and the annual benefit from weed control research in the years 1978 and 1979 was $80 million. All of these returns are calculated on production on North Dakota farms at prices prevalent in the years involved. These are excellent returns on investment, and highly justify additional investment in agricultural research of this type--so badly needed by agriculture.

Durum wheat has been the second most important and valuable commodity produced in North Dakota--overtaken a few years ago by sunflowers. Two new varieties of durum wheat, Edmore and Vic, were released in the 1979-1980

period. Calvin and Cando durum from NDSU were the first semi-dwarf durums produced in North America with high grain quality. Edmore and Vic were the first U.S. durum with high gluten strength desired by some European importers of durum.

New durum varieties in use since 1973 have added $80 million more "durum income" to producers in the 1973-1978 period over older varieties available. For each dollar invested in durum wheat breeding research at NDSU approximately $130 in dividends is returned to North Dakota producers and for the State's economic benefit.

Investment in U.S. agricultural research is substantial and it continues to expand. Numerous studies have shown that past agricultural research expenditures nationwide have high rates of return. However, private investment in agricultural research is restricted because many of the research benefits cannot be captured by a private firm. Thus the public sector must do much of the basic agricultural research. But, it is a good use of our tax dollars, for farmers and consumers alike.

If the United States is to meet its own requirements for food and fiber and fulfill its responsibility to export food and feed to other countries to help satisfy their needs, we must continue to support agricultural research. As a Member of the Senate Agriculture Committee and the Agriculture Appropriations Subcommittee, I will continue to do everything I can to see that agricultural research receives top priority.

You are the future of American agriculture.